NATIONAL CONFERENCE ON

INCREASING HIGHWAY ENGINEERING PRODUCTIVITY

Somerset Hotel
Boston, Massachusetts
September 17-18-19, 1957

Sponsored by

Bureau of Public Roads, U. S. Department of Commerce
American Association of State Highway Officials
Association of Highway Officials of the North Atlantic States
Massachusetts Department of Public Works
Massachusetts Institute of Technology

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Washington 25, D. C.

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OPENING OF THE CONFERENCE

Carl A. Sheridan
Former Commissioner of Public Works
Massachusetts Department of Public Works

Gentlemen - it is my pleasant duty to open this conference. This conference, as you know, is sponsored by the Massachusetts Department of Public Works, the Department of Civil and Sanitary Engineering of the Massachusetts Institute of Technology, the Association of Highway Officials of the North Atlantic States, the American Association of State Highway Officials, and the Bureau of Public Roads of the United States Department of Commerce. I think a little explanation is due. When this conference was planned and conceived, I was Commissioner of Public Works of Massachusetts. When the publicity and the invitations went out, I was still Commissioner. At the end of last month, because of business reasons, I requested the Governor to accept my resignation, which he did on the 12th of this month, and appointed Anthony DiNatale to succeed me as Commissioner of Public Works of Massachusetts. I now take great pleasure in introducing the Commissioner of Public Works of Massachusetts, who will introduce the Governor to you. Thank you very much.

Anthony DiNatale
Commissioner
Massachusetts Department of Public Works

Thank you, Carl, Governor Furcolo. Gentlemen, as the new Commissioner of Public Works of Massachusetts, I extend to you officials and guests of this conference a cordial and hearty welcome. I am certain that this vitally important conference, this discussion of the new methods of highway design together with the presentation of comprehensive reports of specialists in all phases of highway construction, will greatly assist our engineers in their endeavor to construct roads at a minimum of cost and with a maximum of safety. I fully realize, as you do, that this conference will do much to make for better construction results, vastly improved highways, and in the final analysis, a better America. To this, we dedicate this conference. I sincerely hope your stay in the capital city of this rapidly progressing Commonwealth is most pleasant and will always afford you happy memories.

This is always a pleasant task. It is my privilege and pleasure to present to you our distinguished Governor. He is a symbol of loyalty to principal, and a man of unchallenged integrity. Our Governor is a

scholarly man, an experienced leader with a keen pentrating knowledge of State and National Government. He has that rare combination of experience in both State and Federal Government. The public record of our Governor, Foster Furcolo, is a sequence of constructive activity dedicated to making democracy serve as an instrument to promote human happiness and to placing into operation programs to do the most good for the greatest number. Gentlemen, our Governor, Foster Furcolo.

WELCOME TO MASSACHUSETTS

His Excellency Foster Furcolo
Governor
Commonwealth of Massachusetts

It is a very pleasant duty to welcome you all here, and, in the name of all the citizens of the Commonwealth, to greet you and to hope you have every happiness during your stay in Massachusetts, and to also wish that this conference may be a productive one and lead to good and lasting results. I am particularly pleased to be here with Carl Sheridan, with whom I served in the State House when I was Treasurer of the Commonwealth and he was the State Commissioner of Administration Finance. Then, as you know, he headed up the vast empire of roads and personnel that comes under the heading of the Department of Public Works. Carl and I also had the pleasure of serving on the Korean Bonus Committee together. There we had a good many headaches but also some enjoyable times, and I want to join with all of you in wishing him every success and happiness in the career that is now opening before him. It is an extremely important one that is going to see him give service in a very productive way. Best of luck to you Carl, in your new duties and your new endeavors.

And, of course, you do not know our new Commissioner of Public Works as I have had the pleasure of knowing him the last few years. I can tell you without question, however, that those of you who do not know him are going to find in him an adminstrator of outstanding ability, a man who believes in getting things done, and who will give you the cooperation and the drive in the earnest efforts that all of you in this field want. To you Tony, in your new duties, every good fortune and every good luck. The Commonwealth has every confidence in you, and we know you are going to do an outstanding job.

I am also pleased to welcome not only the visiting Commissioners of Public Works who are here, the scientists who are occupied in developing the new devices, the manufacturers and contractors from all over the country, but particularly "Rad" Radzikowski, the Chief of the Division of Development of the Bureau of Public Roads, who is your general chairman, and who has been doing such an outstanding job in the Nation.

Now, I do not know how many people in the country as yet fully appreciate the program that is being undertaken, the construction of the Federal Interstate Highway System. This program may well change the entire course of our economy in the years to come. We, in the eastern States have a problem that many of you from the midwest and the west, perhaps do not have. Here we have many congested areas. It is not the easiest thing in the world to develop highway systems throughout the eastern part of the country. But it is an important part of the country, as a matter of fact, here within a radius of 500 miles of Massachusetts we have 50 percent of the population of the entire Nation, and we have 50 percent of the industrial output of the entire Nation, and from the point of view of the defense, of course, this area is of vital importance. We believe deeply in highways and in what they can mean. We do not think of them only in connection with the ease and convenience of motorists from my own State. We think of them in connection with our entire economy, because we are fully aware that they are essential whether we are talking about regional development; whether we are talking about bringing in new industry which, of course, we all want to do in this State just as in any other State; or whether we are talking about attracting tourists because of our large vacation industry--I might just put in a little plug in passing. We think we have the best vacation State in the entire Nation because we think we have everything here in Massachusetts to attract the tourist whether it be our beaches in Cape Cod; our historic trailways and beautiful spots in the Berkshires and Pioneer Valley; the sights and national shrines here in Boston, Lexington, Concord and throughout the State or whatever it may be--swimming, or fishing, or skiing or anything at all--we have it here in Massachusetts for the vacationist. However, it is not of much value to him and he is not going to take any interest in it unless the means of getting to it meet with his approval. In Massachusetts, we are glad to do everything we can to cooperate in building a highway system that will not only make it easier for those who travel for purposes of enjoyment and entertainment, but will also attract industry and bring about those economies that we all like so much, and which mean so much to the people of any State.

You folks must have the vision in your planning to take into account a vast panorama that covers every activity not only in the State but in the Nation. You also have to be concerned with defense. If you do not have the vision and you do not have the planning, we may find in a few years that we do not have what we should have because you have been thinking in terms of one year or two years or five years. Without question, what you do, what you plan, what you succeed in accomplishing is going to affect, and vitally affect, the economy of the entire Nation, the convenience of all the people of this Nation, not for ten or twenty years, but for a hundred years or more. That is why as Chief Executive of the Commonwealth of Massachusetts, I am delighted to be here with you, to welcome you, to wish you every success in your endeavors, and to say we need what you are doing. Go ahead and do a good job. We appreciate it. The best of luck to you.

Mr. Sheridan: Any endeavor such as this requires a figure to lead, to initiate, and to promote these conferences for the good of all the States of the United States. Mr. Radzikowski of the Bureau of Public Roads has been working diligently for some time in promoting these conferences, and trying to get better roads faster and less expensively, and his efforts and help with the different departments of the United States is shown in the friendliness that these many commissioners have with him. It is with a great deal of pleasure that I introduce to you now, Mr. Radzikowski, who will give us a general outline of the purpose of this conference. Mr. Radzikowski.

OBJECTIVES OF THE CONFERENCE

H. A. Radzikowski, Chief
Division of Development, Office of Operations
U. S. Department of Commerce
Bureau of Public Roads

On behalf of the Bureau of Public Roads, on behalf of the various State highway department organizations sponsoring this meeting, on behalf of the consultants that are here, and on behalf of the various manufacturers and others, we thank you very heartily, Governor Furcolo, for opening this conference and giving us such a good start. Thank you very much.

Thank you Mr. Sheridan, for the very kind introduction that you have just given me. We all felt bad on hearing the news that Mr. Sheridan is no longer going to be chairman of the Massachusetts Highway Commission because of the fact that he did such a wonderful job in developing efficiency in highway work. We have considerable solace in the fact he is still going to be with us in highway operations through the management of a large highway construction firm. He is still going to be interested in highways.

The Governor referred to the fact that Mr. DiNatale had driving power. I had some taste of that driving power when I was a school boy cadet here at South Boston High School. I was a bugler. Mr. DiNatale's brother was the drum major. I can assure you that the DiNatale family had a lot of driving power, because I had to work pretty hard in the drum corps of South Boston High School.

I would also like, at this time, to express appreciation to Professor Miller of Massachusetts Institute of Technology and his staff for the work they have done in organizing this conference; to Mr. Belyea of Mr. Sheridan's staff and Mr. Swanson, Regional Engineer of the Bureau of Public Roads and his staff for the work they have done in organizing this conference; to the staff of the Massachusetts Department of Commerce for their splendid cooperation; and, to

Mr. George Hines, the Washington representative of Massachusetts, who worked very hard for the success of this conference. We also appreciate very much the fact that Mr. A. E. Johnson, Executive Secretary of the American Association of State Highway Officials will be with us and that General L. W. Prentiss and Mr. Burt Miller of the American Road Builders' Association and Mr. George Gaffney of the New England Road Builders' Association are actively participating in and supporting this meeting. We of the Bureau of Public Roads have about 60 engineers here from all over the Nation. Many of our field division engineers and several of the engineers from our Washington office are here. Lastly, I would like to take this opportunity to thank the men who have taken their valuable time to prepare formal presentations for these panel discussions and to come here and present them to you.

Before I left Washington, Mr. Tallamy, the Federal Highway Administrator, and Captain Curtiss, the Commissioner of Bureau of Public Roads asked that I read short messages to you. Mr. Tallamy's message is:

"Gentlemen:

"It is most gratifying to me that you have gathered here in Boston to again pool your knowledge and know-how on the recent developments that have been accomplished in the application of electronic computation and other electronic devices to highway engineering, construction, and operation. You are to be complimented on the progress you have made in developing these applications, particularly the very substantial progress that has occurred since the Los Angeles conference in March of this year. I feel that the use of these electronic computers and other electronic devices will do much to improve not only the economy of highway construction but also the economy of the vast highway system we are now constructing.

"While we are now primarily concerned with the construction of this system and are, therefore, thinking mostly of the machines and devices which will aid us in the design and construction phases of the work, we must also keep in mind the fact that it will be necessary to operate this system in a safe and economical manner. We should, therefore, be equally diligent in our search for new developments that will aid us in the maintenance and operation of this system.

"It is my hope that you will, while you are here, obtain from the formal discussions and from your informal conversations information that will be of value to you in increasing the productivity of your highway engineering work, the economy of your construction operations, and the economy of the transport service you will provide by that construction."

Now the statement by Captain Curtiss, the Commissioner of the Bureau of Public Roads.

"Gentlemen:

"This conference is another step in our effort to increase the productivity of highway engineering. Much progress has been made during the past year and a half. During that time, we have established beyond question the value of the electronic computer to highway engineering operations. Most all of the States, the Bureau of Public Roads, and many of the highway engineering consultants have decided to adopt it in their operations. We are now, therefore, faced with the task of developing the most economical methods and procedures for its use.

"This is a task which you, the staffs of the public highway organizations and the highway engineering consulting firms, must accomplish. The Bureau will do all it can to assist in this endeavor by supporting the development work in this area and by assisting in the interchange of information on the development work accomplished but the primary responsibility must remain with you. You must determine which electronic computer is most suited to your operations and which of the several programs that have been written for highway engineering operations is most suitable for your operations or what changes must be made in those programs to suit the particular conditions in your area. This conference was called to aid you in this work and it is hoped that you will be able to obtain, while you are here, information that will be of assistance to you in this endeavor.

"I wish you a most successful conference and wish again to say that the Bureau of Public Roads stands ready to assist you in every way it can."

That is the end of quote on Captain Curtiss' statement.

These conferences are held for the primary purpose of discussing with you the methods and procedures by which engineering productivity can be increased. We have before us a large road building program and there is very little possibility of being able to obtain the engineering force necessary to complete that program with our older highway engineering methods. We feel, therefore, that it is essential that the highway engineering profession adopt for its use the many new tools and devices that have been developed during the past few years.

We must reevaluate our engineering procedures and processes, our highway construction methods and practices, and determine first, if all the procedures that have been used in the past are essential to our work and second, which of those found to be essential can be improved. This reevaluation must be carried out with the view of reducing the use of our three most valuable commodities--time, money and professional manpower.

The discussions at this conference will cover the uses that can be made of electronic computation in highway engineering; the much greater use that can be made of aerial photography and photogrammetry the very great savings that can be accomplished by combining photogrammetric measurement with electronic computation; the organization of a computer division and the method of intergrating electronic computation into our highway engineering processes; other

electronic devices and processes that have been developed which will aid us in improving engineering productivity and construction processes; new equipment developments which will speed up or improve highway construction and the improvements needed in the administration of highway construction.

As you will note from the program, today's discussions will deal with the use of electronic computation in highway engineering. Three panel discussions are scheduled. The first of these, which will be chaired by Mr. J. W. Johnson, Superintendent of the New York Department of Public Works and Chairman, AASHO Committee on Electronics, will cover the use of the electronic computer to perform the enormous amount of computations necessary in the location and design of a highway. You will note as the discussion on this panel progresses that this type of work is being performed on four different computers. Actually, it has been programed on a fifth make and this also could have been included in the discussion.

The second panel discussion will deal with the use of the electronic computer in bridge design and in the computation of bridge geometrics. Mr. J. L. Morton, Commissioner of the New Hampshire State Highway Department and a member of the Executive Committee of AASHO, will chair this panel. The participants in the formal panel discussion will present to you their ideas as to the methods that can be used in solving the many problems that arise in connection with the design of structures.

The third and concluding panel discussion today will cover the use of the electronic computer in traffic studies and research analysis. Mr. Johnson, who is shown as panel chairman on your program, will not arrive today. We have, however, obtained a very able man to replace him, a man you all know and respect, Mr. John A. Volpe. You will find from this panel discussion that the electronic computer has a very definite place in this work. The panel members will prove to you, I am sure, that work previously all but impossible because of great mass of computation involved, can now be completed in a very short time. One problem solved on the electronic computer in 30 hours, would have required 30 man-years by hand methods.

Directly after the close of this panel discussion you will find available to you in the rear of this room and in the West Foyer of the hotel, demonstrations and exhibits of some sixteen different devices which we believe will be of great assistance to you in increasing the productivity of your engineering forces and in improving the maintenance, construction, and operation of your highways. These exhibits will, of course, be available to you each afternoon through Thursday. I am also sure that you could arrange a more or less private demonstration at any future time convenient to you if you but mention your interest to one of the representatives of the companies.

Tomorrow morning, we will change the locale of our discussions and reconvene in the Kresge Auditorium of the Massachusetts Institute of Technology. We have, we realize, set a rather early starting time tomorrow morning. However, one glance at the full program for tomorrow will tell you why this is necessary. Tomorrow morning, Mr. Ridge and I will moderate two programs which we think will be of very great importance to you. The first of these will cover the organization needed for a computer division and its place in the highway engineering organization. I also expect that the panel members will discuss the methods that have been used to integrate electronic computation in their highway engineering. The second discussion tomorrow morning will be in the nature of a progress report on the progress that has been made in the development of electronic programs for the various makes of computers. Also included will be a discussion of the need that exists for electronic computer service centers and of the type of service we can expect from such centers.

Tomorrow afternoon we will take up the subject of photogrammetry. The first panel which will be chaired by Mr. W. T. Pryor of the Bureau of Public Roads, will cover the optimum use of photography and photogrammetry in highway engineering. They will, we hope, provide you with information that will enable you to obtain much greater value from both photography and photogrammetry in your highway engineering work. The second panel will cover the development and construction of a photogrammetric-electronic computer system for highway location and design. This panel will be chaired by Dr. John B. Wilbur, Head of the Department of Civil and Sanitary Engineering of the Massachusetts Institute of Technology. It will cover the two systems that have been developed so far for the tying together of photogrammetric devices and the electronic computer. At the close of this formal presentation, Professor Miller and his staff at MIT will demonstrate to you a system that they are in the process of developing for this work under a contract with the Massachusetts Department of Public Works. At this point, I would like to call to your attention the fact that this work is being financed by the Massachusetts Department of Public Works and should prove to be a great value to the entire highway engineering profession. We hope that additional work of this type can be accomplished in the near future.

On Thursday morning, we will again reconvene in this room and Mr. J. N. Robertson, Director of Highways of the District of Columbia, and Vice President of AASHO as well as the Immediate Past President of the American Road Builders' Association and Chairman of its Committee on Electronics, will chair the panel discussion on the use of other electronic devices and processes to improve highway engineering and operation. This panel will discuss the use of electronic computers to control the frequency of traffic signals, the use of electronics to control traffic signs, the use of induction radio to convey information to the driver of the motor vehicle through his ears rather than through his eyes, the use of radio communication in highway construction and maintenance, the use of the tellurometer in surveying work and the use of electronics to control construction equipment.

The second panel on Thursday morning will discuss the improvements that have been made in construction equipment and how, we the highway engineers, can

obtain the greatest benefit from those improvements. Mr. Julien Steelman, President of the Koehring Company, and President of the American Road Builders' Association, will chair that panel.

The Thursday afternoon panel which will be chaired by Mr. H. L. Plummer, Chairman of the Wisconsin State Highway Commission, and, I might say, one of our leading highway administrators, will cover the improvements that, we the highway engineers, can make in our construction and contract procedures that would reduce the cost of highway construction to the contractor and ultimately to the highway construction agencies.

Following the close of that panel discussion, Mr. F. V. du Pont will moderate a panel of distinguished speakers who will summarize for our benefit the accomplishments of this conference and tell us what they believe the future holds in regard to the subjects that have been under discussion.

Before closing I would like to emphasize that this is your conference. Throughout the three days, we and the panel chairmen will attempt to hold the formal discussion of the subjects to a minimum and will try to provide a maximum of time for questions and discussions from the floor. You will have, on the various panels, men who know their subjects thoroughly and I urge you to take advantage of this opportunity by asking of them the questions you have on your mind and by presenting for their and the other conferees criticism any ideas you have on the subject under discussion. With that brief outline of the next three days, I will turn the rostrum back to Commissioner Sheridan.

It is my hope that you thoroughly enjoy the coming discussions and that you will be amply repaid for your attendance at this conference.

We also again want to thank the Governor for stopping from his busy day to get this outline. I am sure you can now see how busy the Massachusetts Highway Department is and the worthwhile work that they are doing. Thank you again for giving us your time. We know you are very busy and we certainly will remember how kind you were to come here and help us out.

Discussion on

The Use of Electronic Computation to Expedite

Highway Location and Design

Moderator

John W. Johnson--Superintendent, New York Department of Public Works and Chairman, American Association of State Highway Officials' Committee on Electronics

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Glen Ryden--Arizona State Highway Department

Lawrence M. Saunders--New York Department of Public Works

W. D. Vanderslice--Missouri State Highway Department

L. E. Davidson--Illinois Department of Public Works and Buildings

Philip King--King and Gavaris, New York, New York

Mr. Sheridan: The moderator for this panel is one of the foremost highway administrators in the country. We are very honored that he accepted the chairmanship of the panel and I know that you all are going to enjoy this very important discussion. I want to introduce to you, Mr. J. W. Johnson, Superintendent of the New York Department of Public Works, and Chairman of the American Association of State Highway Officials' Committee on Electronics. Mr. Johnson.

John W. Johnson
Superintendent
New York Department of Public Works

I am very grateful to be able to serve as your panel moderator for I find that the assignment has been of great help to me. It has made it necessary for me to do a great deal of studying on the vast stores of material which I have received from Mr. Radzikowski, all within a definite time. You know how it is--numerous papers cross your desk which are just chock-full of important data that you intend to digest at some future time only because at the moment you are too busy. This problem seems to be always with us because spare time never seems to arise. Therefore, at the moment, I am much better off than I would otherwise have been, as during the past ten days I have done considerable reading.

The review that I have made indicates that a great deal of effort from all over the Nation is going into the attempts to increase highway engineering productivity. It is the widespread consensus that old engineering procedures must be either discarded or improved as rapidly as possible. By our presence here at this conference we give evidence that we approve this action for we well realize that, if we are to meet the greatly magnified construction schedules with an engineering force which, for most of us, has dwindled below its normal complement of just a few years ago, we must do something.

Our hope for a solution rests in this and in similar conferences which have already been held at various other areas throughout the country. We are blessed with the great leadership of the men and organizations who have developed and guided these sessions for the purpose of pooling the knowledge and reporting the techniques of the accomplishments which have already been made.

I note the need for caution, however, as there are evidences of impatience which could result in needless or wasted effort. No group or State can expect, by itself, to develop the means to use the newly

developing tools to meet all of the present needed requirements. Rather, some time must pass to allow for organization, inventory, and scheduling before we can expect to have the oft-lamented missing cooperation for freedom of exchange. Fortunately, our great Bureau of Public Roads, the American Association of State Highway Officials and other inspired groups are taking steps to unify all willing efforts.

Last fall, prior to signing the contract to procure our electronic equipment, we were told that delivery would not be possible for two years. This was not good--still other manufacturers could do no better. There was one advantage, however, in that it would give us a sufficent period of time to train the necessary personnel and generally organize and establish programs for our needs. Then what happened? Shortly after the rental contract was signed we were told that the equipment would be available in six months. In the frantic rush that followed, several of our people were hurried off to schools, and an almost hopeless canvass for mathematicians and programers was undertaken. Finally, when the devices were installed, I was quite pleased at our efforts because of the number of experts I thought we had acquired. The shock was great when I found that most of those clustered around the equipment were employees of the manufacturer.

It was not easy to convince many of our top people that most of the old methods must now give way. There was much evidence of an almost antagonistic feeling that earthwork computations could never be made if cross sections were to be so greatly reduced in number. It seemed by then that everyone was trying either to get in or out of the act. The purse string boys were definitely in. They were concerned of the expensive rental, then they were disturbed that the machines were idle at times.

One day telegrams went out to all of the District offices with strong orders to get in field data as rapidly as possible so that the computers would be kept in full operation. This was horrible because the chief engineer's office was at that time working on instructions of a manner of reporting this material to the various District offices. Much of our hard won gains were lost by this episode. Happily, we caught the pieces in time. We had to be quite severe in dictating that no one but members of the electronic division group could become involved in any orders for scheduling.

We have a distinguished panel of men who will discuss with us their work in: "The Use of Electronic Computation to Expedite Highway Location and Design." I have seated these gentlemen from left to right which will also be their speaking order.

At my far left is Mr. Glen Ryden, Chief of the Computing Division, Arizona State Highway Department. Mr. Ryden has been with his department for 26 years. He has spent a great deal of time perfecting and developing programs for their Univac 120. He also presented a paper, at a similar conference, on "Increasing Highway Engineering Productivity" in Los Angeles, California, in

March of this year. Mr. Ryden has been singularly honored--for in June of this year, the Western States Highway Officials at their annual conference in Texas presented him with the Dr. L. I. Hewes award for outstanding contribution to highway development in the West during 1957. This award stemmed from his activities in connection with electronic equipment.

Our next panelist is Mr. Lawrence M. Saunders, Assistant to the Chief Engineer, New York State Department of Public Works. Mr. Saunders has been with his highway department for 30 years. His background of structural design, followed by highway design and construction has made him the mainstay of New York State's newly created electronic division where he is devoting much of his time to the organization of program preparation.

Next we have Mr. W. D. Vanderslice, Senior Engineer, Missouri State Highway Department. Mr. Vanderslice is in charge of computer application development. He also participated in the Los Angeles conference and it was here that he expressed concern over the lack of cooperative interchange between States of programs for electronic computers. Mr. Vanderslice, it is expected that your disappointment will be short lived. Friday of this week we expect to inaugurate the initial work of the Electronics Committee of the American Association of State Highway Officials which has as one of its purposes the cooperative program exchange that you are seeking. I have studied, with a great deal of interest, the earthwork program which you compiled for your State and I compliment you for a splendid piece of work. This, I received from the library of the Bureau of Public Roads.

Our next panelist is Mr. L. E. Davidson, Supervisor, Electronic Computer Unit, Bureau of Research and Planning, Illinois Department of Public Works and Buildings.

Mr. Davidson's bureau has also developed an earthwork program for the electronic computer. We wish that he would also take back our compliments of a job well done.

Fortunately, or unfortunately, the depth of top soil in the State of Illinois is so great that we find that the earthwork program as presently prepared has not taken into consideration any other type of excavation. It would be of interest to know whether you plan to develop this further or whether this will be sufficient for all of your needs.

On my right is Mr. Philip King, partner in the firm of King and Gavaris, Consulting Engineers, New York City.

Although we were familiar with Mr. King's fine ability in the design of highways and structures which he has undertaken for the State of New York, we were greatly impressed with his unusual engineering background and experience. This young man was supervising engineer on a supersonic wind tunnel; a

synchrocylotron, high altitude balloon launching facilities; a steel forging plant; a pilot plant for the Atomic Energy Commission and that is not all--he has designed a synthetic rubber plant and last but not least, a whole flock of breweries. We should be flattered in that he seems to have chucked away all this fun and glamor to go to work on the highway problem.

Gentlemen, we give you a very fine and representative group of experts for this discussion.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

R. Glen Ryden
Arizona State Highway Department

UTILIZING ELECTRONIC COMPUTERS TO INCREASE HIGHWAY ENGINEERING PRODUCTIVITY

In December 1955, I was introduced to the Univac 120. I was very much impressed by the speed and accuracy in which this computer could solve vast quantities of computations in such a short period of time.

The electronic computer is no longer a mysterious machine as it is now being used daily for engineering calculations by many of our State highway departments, private engineering firms and by many of our government agencies.

There are several things to consider in making such drastic changes over the conventional way of doing our computations. It is only natural that people fear the unknown and the human tendency to dislike change.

My first consideration was to avoid changing the customary manner in which the field notes are normally kept. I did request better spacing of the notes. I also wanted to make the key punching operation as simple as possible, as at times we may have help that have no knowledge of engineering do the key punching.

The grades and alignment data are computed in a continuous operation through station and level equations. The results of these calculations are tangent grade elevations, vertical curve corrections, corrected finished grade, rate of super per foot of roadway width for the Hi and Lo side of the curve, and widening if needed on sharp horizontal curves. The crown slope rate is also punched into each card on tangent. The alignment data is computed on a gradual transition, from the tangent section through the various points on the curve and back to tangent.

The level books must be coded and prepared with the following information prior to key punching: P.I. point elevations, vertical curve starting station with the length of vertical curve and maximum corrections, grade rates between the P.I. points and the rate of crown for tangent, the base super rate at the various points on the curve with the diminishing or ascending rates used for computing the super through the transition sections. This information is punched into the grade cards by the key punch operator. A grade card is key punched for each cross section point so that a calculated grade will be available for each of the cross section cards.

TYPICAL SECTIONS REVERSE CURVES

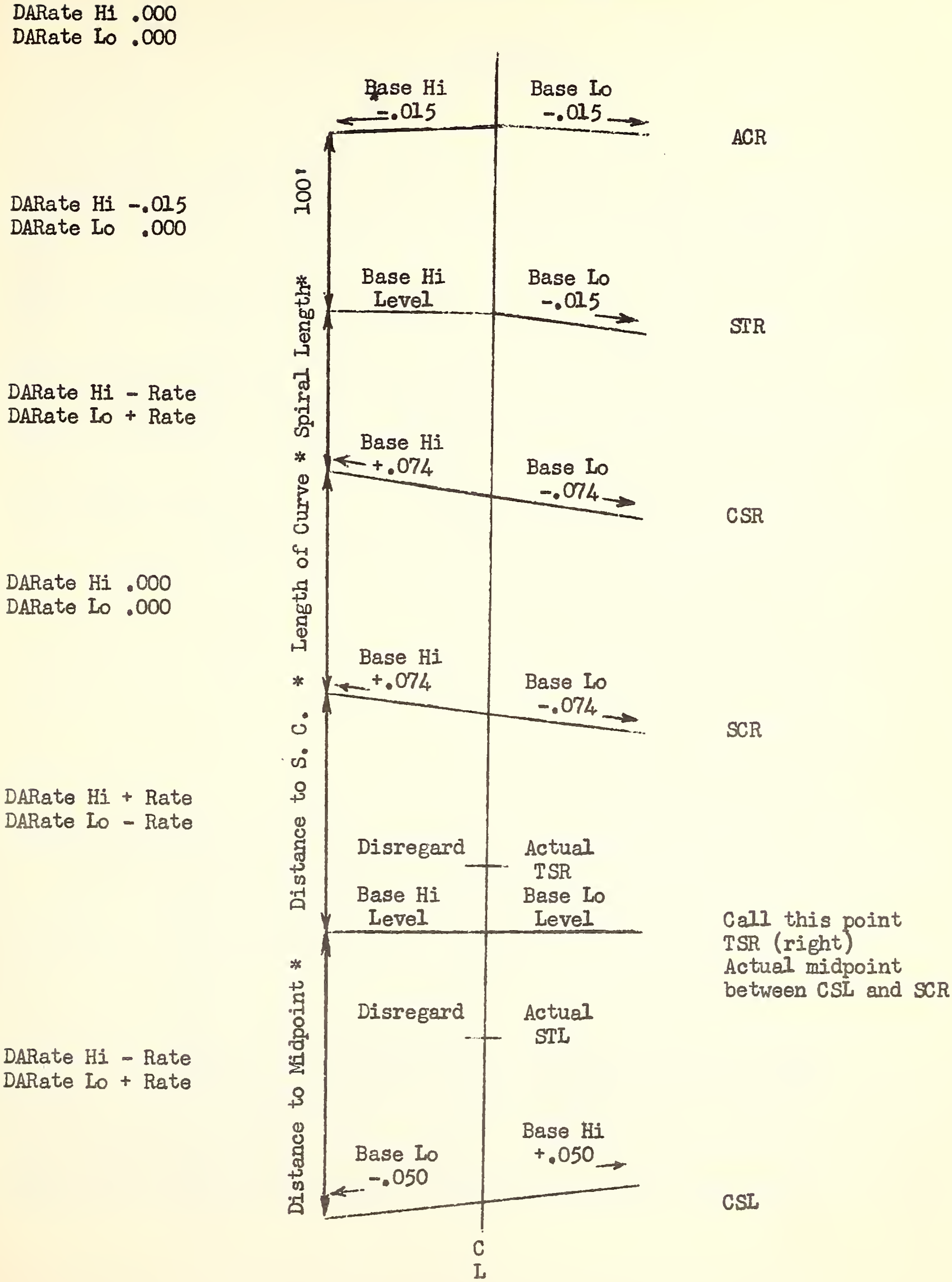


Exhibit # 1
Grade Card

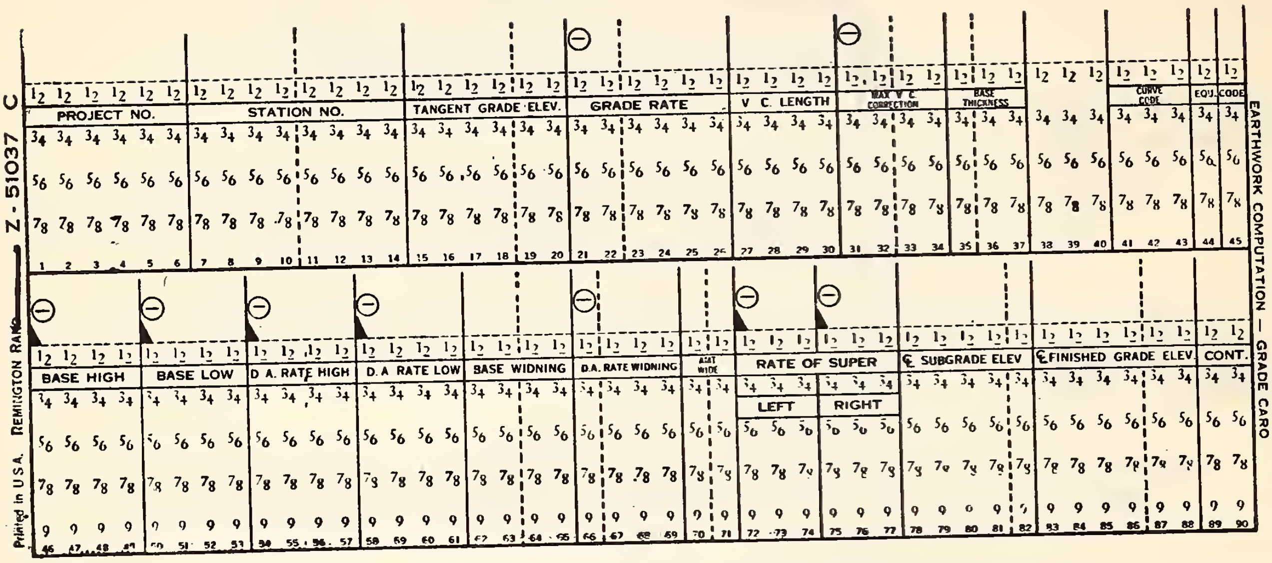
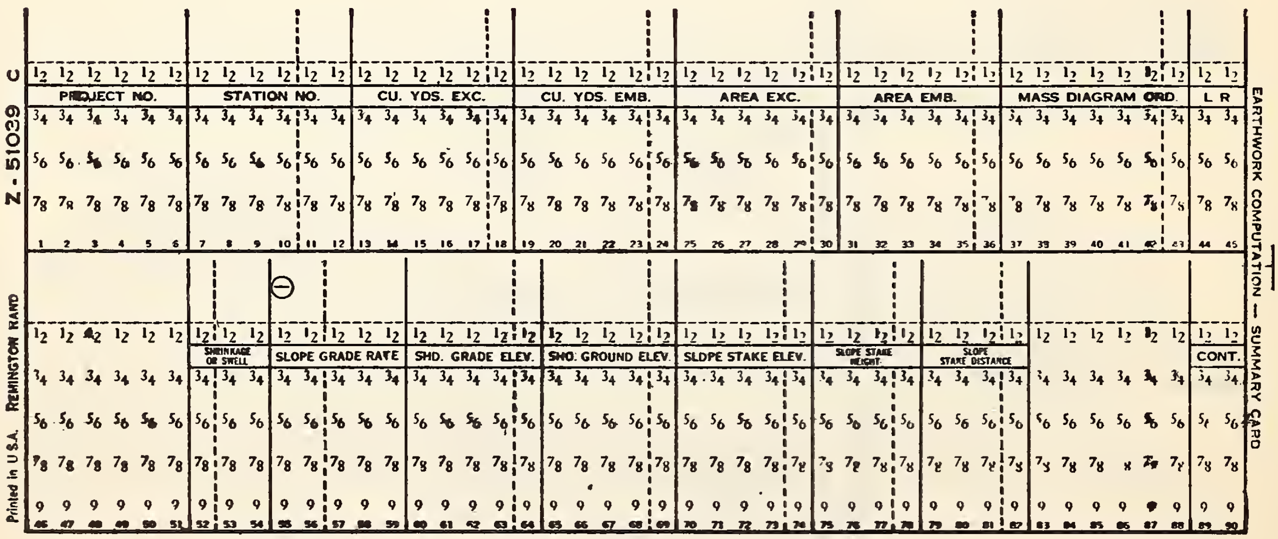


Exhibit # 2
Summary Card



The following logic and reasoning was considered in developing this application; One grade card is key punched for each cross section reading. The cards through a tangent section of the roadway will have a lead card enter the computer first with the rate of crown slope key punched into the card. The diminishing or ascending rate will be .0000 for the left and right half of the roadway as no change is desired in this crown rate through the tangent section. This rate of crown slope will be punched into all cards until the next load card for alignment data, coded B.S Left or Right (before spiral left or right) comes under the sensing section of the Computer. This card will have new bases and rates. The base Hi and Lo on this card would be -.015 on the left and -.015 on the right (this is the normal crown rate per foot of roadway width used in Arizona). The D.A. (diminishing or ascending) rate for the Lo side of the curve would be .0000 as no change is wanted for the low super rate of -.0150 up to the next point which is the T.S. left or right (tangent to spiral left or right). The D.A. rate for the Hi side of the curve would be the crown rate of -.0150 divided by the distance between B.S. left or right and T.S. left or right. This would be a plus rate in order to raise the crown section to a level section at the T.S. on the Hi side of the curve. The new bases and rates at the T.S. left or right would be Base Hi .0000 Base Lo -.0150. The D.A. rate Hi would be the maximum super rate for the curve divided by the distance between the T.S. and the S.C. (Spiral to curve). This would be a plus rate. The rate for the Lo Base would be the same except it would be a minus rate. As the rates are computed for the Lo side each one is tested against a -.0150. We want nothing less than a -.0150 punched into the grade card on the low side of the curve. If the test shows the computed rate to be less than -.0150 the computer will punch a rate of -.0150 for the Lo side. If greater the calculated rate will be punched into the card. The rates for the Hi side are punched as calculated. The next point on the curve would be SC (spiral to curve) left or right. The Base Hi would be a plus maximum super and the Lo side a minus maximum super. The D.A. rates would both be .0000 as no change is desired through the center portion of the curve. The same process is used going out of the curve but reversing the signs for the D.A. rates. The calculated rates are punched for both the Hi and Lo sides through a reverse curve. Simple curves are computed by using the same program.

The computer calculates the grades and vertical curve corrections in nearly the same manner as we do on a desk calculator except that the distances into the vertical curve are all checked against 1/2 the length of the vertical curve to determine whether we are in the first or second half of the curve. 1/2 VC Length - Dist. = ± Result. If a plus result, continue

$\frac{\text{Dist.}^2 \text{ X Max. Corr.}}{1/2 \text{ L}^2}$ = Vertical Curve Correction. If a minus result, add 1/2 the length of curve to the P.I. station to establish the vertical curve end station. Then the first station beyond the P.I. station is subtracted from this end station. This result is then squared and we proceed with the vertical curve formula. We automatically drop the curve formula when we reach the end of the vertical curve.

The total time to key punch and verify punch an average mile of grade cards is about 2 man hours. This time is based on 3 to 4 readings per station. The computer time for the new one computer pass, grade program, is about 2 minutes per average mile.

To compute and check an average mile of grades and alignment data the conventional way is about 8 man hours. This is a saving of about 75% of the total time by using the Univac 120.

This application is very flexible in that the grade changes can be made on any desired section without disturbing the balance of the grade cards. The alignment portion of the program handles simple curves, spiral curves and reverse curves, calculating the super rate correctly through the curve transitions.

The computed grade cards are tabulated and the grade elevations spot checked against the profile. A check at this point is rather important as incorrect grades used in computing areas would require a lot of unnecessary rework.

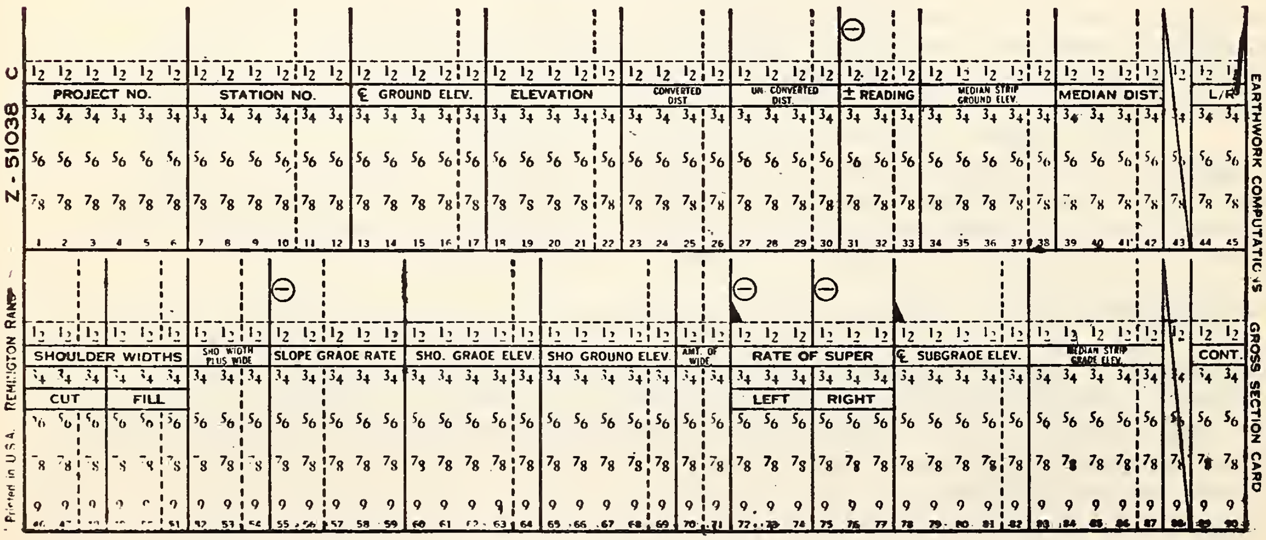
Working our operation in stages a good feature as we can inspect our work as we progress through the computer passes.

The grade cards would now be ready to reproduce the grade and alignment data into the preliminary cross section cards. Each grade card station number being matched against a cross section station number. All non-matched grade cards being out sorted.

Each cross section card will have the center line subgrade elevation and super rate per foot of roadway width reproduced into it.

We planned our programs so that we carry as much information in our cards as possible. By so doing we save the computer storages for calculated values.

Exhibit # 3
Cross Section Card



Column 1 - 6	Project Number - keypunched
Column 7 - 12	Station number - keypunched
Column 13 - 17	Center line ground elevation - keypunched (first card only)
Column 18 - 22	Elevation first reading - keypunched (first card)
Column 18 - 22	Elevation second reading, third, fourth etc. for as many cards as needed to complete section. (one reading per card) keypunched
Column 23 - 26	Normal offset distance - keypunched. This field is left blank when a line change is to be used.
Column 27 - 30	Offset distance to be converted by line change program - keypunched
Column 31 - 33	+ readings - keypunched. If notes are taken to ± readings this field is used. These readings are reduced to elevations and the Univac punches the correct elevation into Col. 18 - 22
Column 34 - 38	Median strip ground elevation - Computed by Univac
Column 39 - 42	Median strip distance from center line - keypunched
Column 45	L for left or R for right - keypunched
Column 46 - 51	Designed shoulder widths - key punched. From these widths the computer determines which width will be used for the cross section.
Column 52 - 54	Shoulder width used - Punched by Univac
Column 55 - 69	Values computed by Univac
Column 70 - 87	Reproduced grade information from original grade cards.
Column 89 - 90	Control codes - keypunched

Our program is so planned that it will select the proper slopes required in cut or fill to conform to our designed roadway section. We may vary our roadway widths by punching the desired widths into Columns 46 - 51. One half of the roadway section could be changed without affecting the other half.

It requires approximately 6 to 7 man hours to key punch and verify one mile of average cross section cards, depending on the number of readings and cross sections per station.

A center line control for the horizontal measurements common to both the grade elevations and the ground elevations must be used for this program. If an office line change is to be used, the original cross section cards must be revised to have all horizontal distances referenced to the left or right of the new center line.

The grade elevations are always subtracted from the ground elevations. This gives us a positive value for a cut and a negative value for a fill. The calculations start at a center control and work out to the slope stake point or the median strip control point. Each half of the roadway is computed independent of the other.

Special cut or fill slopes may be used wherever needed.

To compute the shoulder grade and ground elevation we must first test to find out if the first reading is before or beyond the shoulder distance. For the first testing, the computer will use the shoulder width for a cut section. If the reading is before the shoulder we continue to the second reading etc. until we find the first reading beyond the shoulder. The last elevation and distance will always be held in storage. Then we subtract the last elevation from the next elevation (which was the first reading beyond the shoulder) to get the difference in elevations. Next we subtract the last distance from the next distance to arrive at the distance between these points. The difference in elevation, which could be a negative amount is then divided by the distance. The result is the plus or minus rate of rise or fall on the ground between these points. The shoulder distance minus the last distance times the rate of rise or fall equals the amount of rise or fall. This amount added to the last ground elevation equals the ground elevation at the shoulder. Always adding these plus or minus amounts to the last elevation. The minus amount would lower the elevation, the plus amount giving a higher elevation. To compute the grade elevation at the shoulder we multiply the super or crown rate times the shoulder width giving us a plus or minus amount of rise or fall. This amount added to the center line subgrade elevation equals the grade elevation at the shoulder. At this point we test to determine whether we are in cut or fill at the shoulder by subtracting the grade elevation from the ground elevation. If we get a negative result the computer will pick up the shoulder width for a fill and recompute.

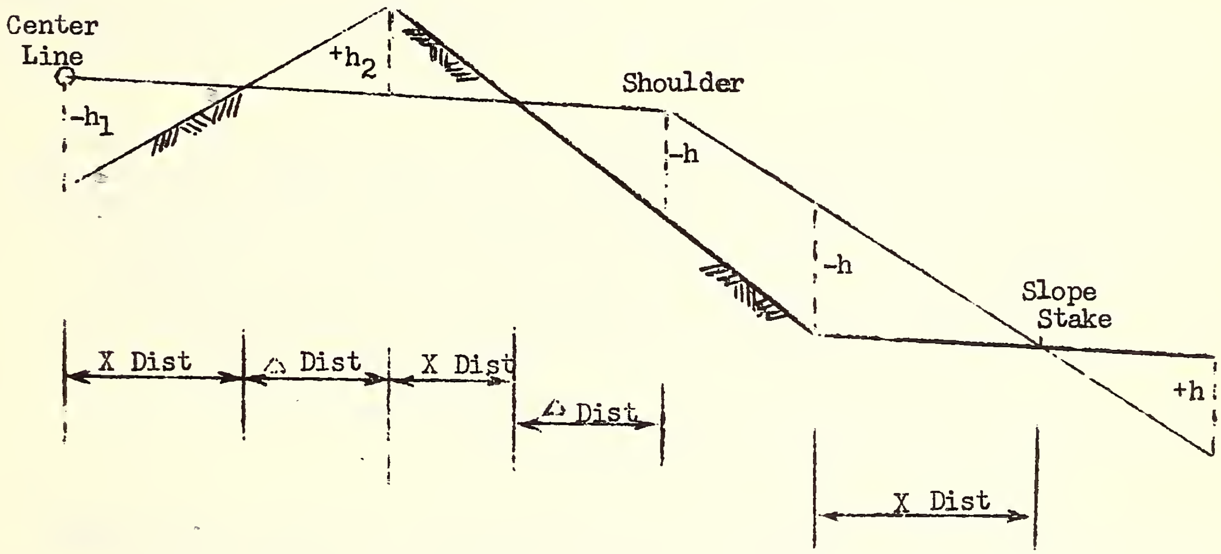
After determining the shoulder elevation the computer is programmed to add a control distance such as 30 feet to our previously determined shoulder width. This distance is used, as we use a 6:1 slope to a distance 30 feet beyond the shoulder. Upon reaching this distance on a 6:1 slope we use a variable slope to a maximum of a 2:1 slope. These slopes are used for both cut and fill on our interstate standards.

The next step is to find out if the next reading is before or beyond the shoulder distance plus 30 feet. If it is before, we continue to the next reading etc. until we reach the first reading beyond the shoulder distance plus 30 feet. This ground elevation is computed in the same manner as the ground elevation at the shoulder. The shoulder grade elevation subtracted from this ground elevation equals the height at the shoulder distance plus 30 feet. This height subtracted from 5 feet is a test to determine whether we use a 6:1 slope or possibly a variable slope. If less than 5 feet we use 6:1 slope. If greater than 5 feet we may use a variable slope. We now test by subtracting this height from 15 feet. If greater than 15 feet we use a 2:1 slope. If less than 15 feet we use a variable slope. After determining which slope is to be used the selected slope rate will be punched into the card. If a variable slope is used we must subtract the grade elevation at the shoulder from the ground elevation at the point of shoulder plus 30 feet. This amount divided by 30 feet would equal the rate of slope for the variable slope. If selected, this rate would then be punched into the card. This completes one pass thru the computer. On the next computer pass the deck is placed in the card receiving section upside down and using the same program boards the computer reproduces the slope stake distance and slope grade rate into all preceding cards.

We will next compute the slope stake height, slope stake elevation and slope stake distance and area of cut and fill.

The areas are computed by the trapezoidal rule. The grade elevation is subtracted from the ground elevation to get the "h" readings at all terrain breaks. A positive value represents an "h" in cut and a negative value an "h" in fill. The last "h" is stored in the computer and compared with the next "h" to determine whether they are both in cut or fill or one is in cut the other in fill. If they have unlike signs the formula for computing cross over points is used.

See Exhibit #4



Proceeding from the center line to the slope stake catch point the next "h" which is h_2 will become h_1 as the next h_2 is compared etc. $\pm h_1 - \pm h_2$ = Sum of the h's
$h_1 \times d_1 = h_1 \cdot d_1$ $h_1 \cdot d_1 \div$ sum of the h's = X dist.

d_1 - X dist. = $\triangle$ dist. After leaving the shoulder of the roadway this formula is used only to the point of X distance. As this becomes the slope stake catch point.

Card design must enter into this work, as well as the programming. All variable values are punched into the cards making the program more flexible. Results from a computer pass punched into a summary card may be reproduced into all the other cards by placing the deck into the card feed in an upside down position. This feeds the summary card into the computer first, making it possible to reproduce any values desired into all the previous cards. The values computed and punched into the summary cards are sometimes needed in the first cards entering the computer for the next computer pass.

Benching of the cut slopes is also programed but is not used at the present time in our designed roadway sections.

The rock areas are computed in the same manner as regular areas only using the rock elevations for the rock ground line. Subtracting the rock area from the total area would equal the area of earth material.

The volumes are computed by the average end area methods. The shrinkage or swell factors are gang punched into the summary cards Columns 52 - 54. All the other values in the summary card are computed by the Univac. See Exhibit of Summary card on page 3.

The summary cards are sorted from the deck as the areas are computed. After the volumes are computed a tabulation is made of the summary cards showing all the values computed. The time required to compute the areas and volumes for an average mile of single roadway the conventional way with an average of four cross sections per station and from 7 to 8 readings to each cross section is about 85 to 100 man hours. The total time to do these same computations by Univac 120, including key punching and verify punching of the grades and cross section cards including preparatory work is about 10 to 12 man hours.

We have found that quantities computed electronically are far more accurate than those computed by conventional methods.

In the past the designers and draftsmen have been used to working with plotted cross sections. Now that we do a great deal of our work electronically we have no cross sections for them. However we do plot a few sections at drainage sites and for special study. There are plotting machines on the market that plot cross sections from tape or cards. In time we expect to use one of these machines.

Another program in use and proven to be a great conserver of man hours is the computing of the areas and volumes from slope stake construction notes. The time required to key punch and verify an average mile of notes is about 6 man hours. The Univac computes these areas and volumes in about 4 minutes per mile.

The following programs are in use or various stages of development. Traverse program, computes the sine and cosine, DX and DY coordinates and the X and Y coordinates. The known values being the length of leg, starting X and Y coordinates, angle or azimuth. The closure error corrected and the area computed.

Each course requires about 7 seconds to compute on the Univac.
Several Traffic study programs are now in successful use.
Bridge design programs are in various stages of development
Storm sewer design program completed.
Soil screen analysis program completed.

We are using a centrally located processing and computing unit. This installation is shared by the engineering and accounting divisions. The engineering work is supervised by the chief computer. The accounting work supervised by the chief of the tabulating division. The directing personnel of the engineering operations should be a graduate engineer or a person with a great deal of engineering experience and trained in the use of the computer including programming.

If all the new tools available to the engineering profession are put to their full use, I see no reason why we could not double our productivity, limited only by our vision and our ingenuity in adapting them to our needs.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Lawrence M. Saunders
New York Department of Public Works

PROGRESS MADE BY NEW YORK STATE ON ELECTRONIC COMPUTATION IN EXPEDITING HIGHWAY LOCATION AND DESIGN

In the New York State Department of Public Works we have had an IBM unit since 1935. Our plan for this unit was to assume the load of several accounting problems, some traffic count problems, a highway expense and a highway needs program, then by additional personnel accompanied by changes and additions of more modern machines take on larger and more complicated engineering programs. Our "650" IBM computer was installed about the middle of May of this year.

Like several other States we started to revise the Kibbel Blaylock Cut and Fill program to fit our needs. Some of the features that we have successfully programed include the taking of terrain shots from a baseline and then designing the road from a centerline. The necessary offset information is fed to the machine on the road card which also contains elevation of completed road. Our terrain cards use HI elevations, offsets and + or - rod readings. Some of our district engineers vary the backslopes considerably on cut sections. To take care of this we punch the desired backslopes for cut sections on each side into the road cards.

For the backslopes on our fill sections we specify on a constant card the height of the pt of shoulder above the terrain below which we use a 1 on 4 slope and above which we move the shoulder out 18 inches or more for a cable or beam type guide railing and then go down on a 1 on 2 backslope. We use half typical sections the control points of which are tied in by coordinates to the centerline of completed pavement. The "650" selects its own typical section depending on the cut slope called for or the distance of the point of shoulder above the terrain for a filled slope.

On our constant card we also can put in a constant to take care of additional area to be added to the cut area to approximate the rounding at the top of a cut slope and a constant for additional area to be added to the fill area at the edges of pavement and over the foundation course.

On our pilot jobs we had considerable trouble with the outside terrain shots not being out as far as the catch points. To overcome this we programed a subroutine to move the outside terrain shots out a distance of 50 feet on either side on the same slope as existed prior to the move.

In our New York State practice if a centerline comes back and coincides with a baseline, we then proceed along the baseline with the baseline stationing. This necessitates an equality between the centerline and baseline stationing at the P.I. which we take care of by a special equality card inserted between the sections on either side.

At present we are programing a subroutine whereby we can discontinue one set of typical sections with their constants and insert a new set of typical sections with new constants. This might occur in going from a strictly rural section to a village street or vice versa. The trick is to compute the correct volumes in the transition section and correctly carry on the summations.

Some of the desirable features on our program include the use of multiple H.I.'s. In the southern part of our State it is not unusual to have as many as eight H.I.'s across a section. We put the shots for only one H.I. on a single card. We do not repeat the last shot in order to fill out a card but leave it blank.

We think the arrangement of a centerline and baseline contribute to flexibility and economy in design. After the first run on the "650", it is comparatively easy to shift the centerline or raise or lower the grade. All we have to do is punch our new road cards where the changes occur.

We apply our compaction factors to the cut volumes as we think it applies the correction at the source. We can then change our compaction factors for different parts of the project, and it would make no difference where the material was used. I learned at Endicott this last week that some States apply their factor to the fill volumes.

We have our program for final earthwork or pay quantities written, and it is now being tested out. In this we simply cut out the road and typical section cards and substitute the final survey cards. It is our hope that unless a preconstruction survey is made to be able to utilize the terrain cards from the design program in the final program. The program for final quantities thus gives several answers that are of little use other than checking between the two programs.

Finally, we have the program for traverses with balancing from California and also one written by the computing center of Cornell University. The consulting engineers in New York State make considerable use of the Cornell Program. We require the consultants on State road work to compute the coordinates of their P.I.'s to the State coordinate system and work to second order accuracy; i.e. 1 in 10,000. This means that their surveys must tie in with the U. S. Coast & Geodetic triangulation stations. The State is desirous of tying in more of their own road surveys in the future with the State coordinate system. The question of the degree of accuracy we should use is being considered. If the degree of accuracy was lowered to third order; i.e. 1 in 5000 there is considerable data put out by the U. S. Geological Survey on transit traverses that could be utilized and thereby save considerable expense in tying in our road surveys. I would like to hear what the other States are doing with this problem.

Besides the above engineering programs, we are working on two bridge programs, and we have completed five traffic count programs besides a program for computing weighted average bid prices.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

D. W. Vanderslice
Missouri State Highway Department

CLASSIFIED MATERIAL CALCULATIONS

The Missouri State Highway Department does not follow the normal pattern in other States of taking bids for earthwork construction on an unclassified material basis. The reasons behind this decision are as follows: The Ozark region contains large quantities of limestone, sandstone, chert and other undesirable material that is difficult to excavate and move. Experience has shown that the bids for the excavation of this material run five to ten times as high as the bids on the easier to handle material. When contracts are let on an unclassified material basis, the bid prices reflect the cost of moving the more expensive material rather than giving consideration to the fact that the project may contain large amounts of lower cost materials. The classification of material excavation provides a saving on bid prices many times in excess of the extra effort required to make the classification.

All contracts payments in Missouri are made from preliminary plan estimates, rather than from final pay quantities.

The statements in this and the above paragraphs indicate the need for careful and accurate earthwork calculations and subsoil investigations. Geologist reports are made on all projects. These reports indicate the material types found on the project and the elevations of dividing planes. The elevations to the layers of rock and other materials are determined from borings made by a power auger mounted on a four-wheel drive truck. This information is used in the calculation of cross sectional end areas.

The calculation of variable type materials on the electronic computer consists of one basic action. This is the calculation of the area between the ground line and the roadbed line, and then looping the computer instructions back to replace the ground line by the rock line and calculating the new area between the rock line and the roadbed. The difference between the new area and the old indicates the amount of earth in the upper layer of material, and the amount of rock is shown by the lower.

A second rock line can be used to replace the first rock line and the end areas between these two lines calculated in a similar manner as before. This process can be continued through as many layers of material as required.

The design data and rock information is entered on special design sheets by the designer for use in making keypunch cards. A sample design sheet is shown on page 3. The cross-section sheet calculated from this

information is on the following page. The cross section at Station 18+00 has been set up to show how two separate rock lines can be handled.

The computer is instructed to loop through additional rock lines by giving the last rock shot a negative sign. This indicates to the computer to read another design card and use this information to compute the additional layer of material.

The rock lines are entered on the design sheets. The computer selects the proper rock slopes and applies rock benches in accordance with the rock code. This code is as follows: A rock code of four indicates to the computer that the section is to be benched right and left. This means that vertical rock slopes are applied in the rock material and a flat slope is followed across the rock top until intersection with the normal slopes. A rock code of five indicates no bench right or left. This means that vertical rock slopes are continued through the rock line to the ground line. Rock code 6 indicates no bench left, a code of 7 indicates no bench right. Rock code five is used to process sections containing more than two types of earth excavation.

The following description is for the preparation of design cards and sheets: The Class A material referred to is easily excavated material of non-rock type. Class C material is rock material.

The design sheets are used for entering design information applicable at individual sections. This information includes the station number, profile grade elevation, super rate, shoulder, or pavement widening, and rock line elevations.

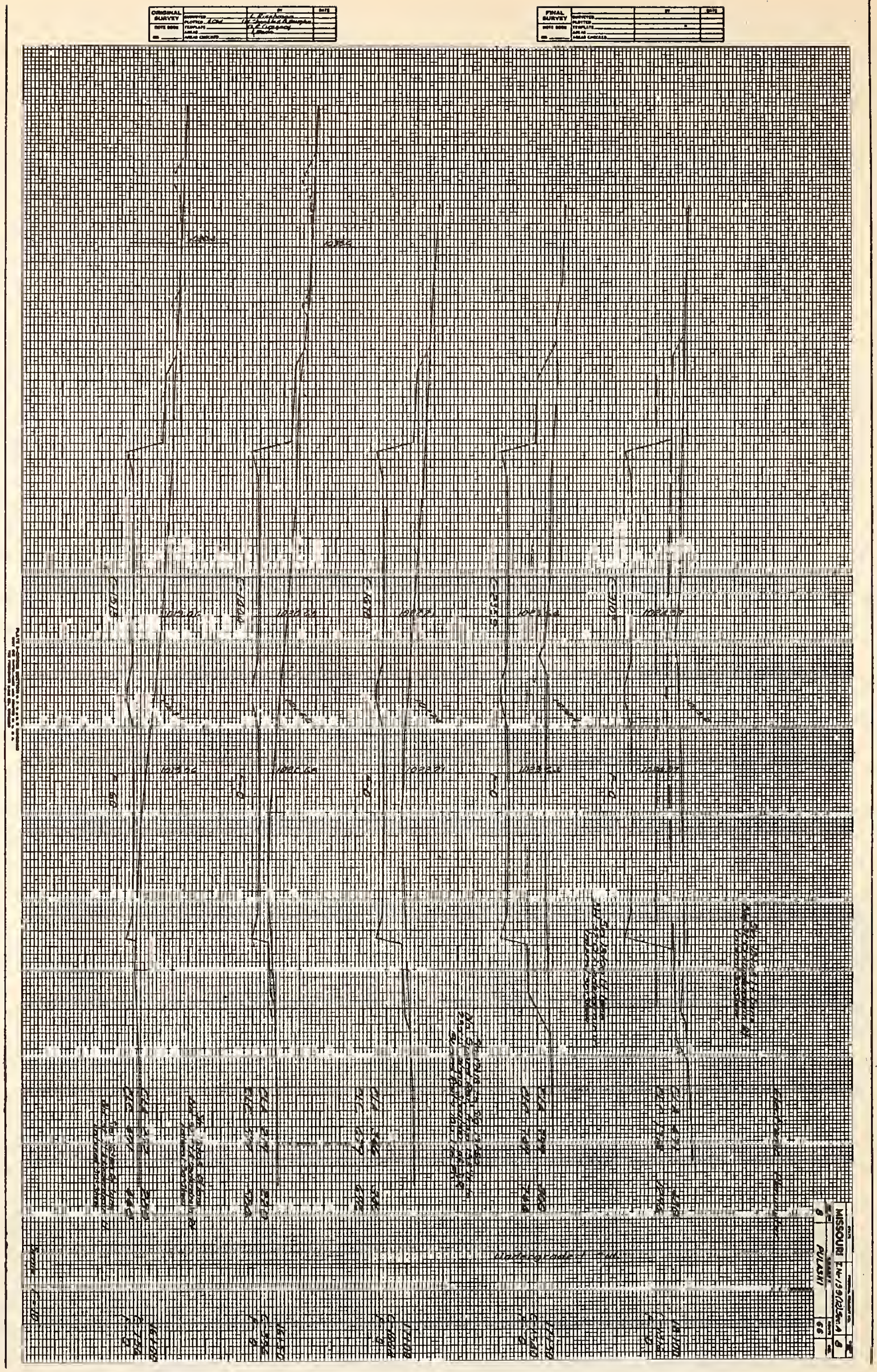
A sample design sheet is on page 3. It was prepared for the cross-section sheet on page 4. The headings on the design sheet columns have the meanings shown in the list below.

Column Headings		Explanation
CO. 1-3		County number
RTE. 4-6		Route number
DTS. 7		District number
ROCK 8		Rock Code
SUPER 9-11		Superelevation rate
STATION 12-15-17		Station number
PAV'T. ELEV. 18-21-22-23		Profile grade
MED. 24		Median or section code
PAV'T. MOD. 25-27		Pavement modification
SHLDR. MOD. 28-30		Shoulder modification
2L	31-25	Left Rock elevation #2
	36-46	Left Rock offset #2

DESIGN SHEET

EARTHWORK CALCULATIONS
MISSOURI HIGHWAY DEPARTMENT

CO.	RTE.	DIST.	ROCK	SUPER	STATION		PAV'T ELEV.		MED	LT. SH. MOD	RT. SH. MOD.	2L		1L		℄		1R		2R	
1-3	4-6	7	8	9-11	12-15	16 17	18-21	22 23	24	25-27	28-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80
085	066	8	4	000	0016	00	1019	06	0	000	000	00000	00000	10257	09300	10210	10000	10190	10540	00000	00000
					0016	50	1020	68						10282	09300	10235		10215	10500	10224	10700
					0017	00	1022	21						10290	09300	10251		10251	10450	10260	10650
					0017	50	1023	64						10297	09300	10275		10277	10700	00000	00000
					0018	00	1024	97						10340	09300	10330		10350	10800	00000	00000
085	066	8	5	000	0018	00	1024	97	0	000	000	0000.0	00000	1030.0	0930.0	1030.0		1030.0	1080.0	0000	00000


ORIGINAL SURVEY
FINAL SURVEY
MISSOURI
PULASKI

Column Headings (Cont'd)		Explanation (Cont'd)
1L	41-45	Left Rock elevation #1
	46-50	Left Rock offset #1
L	51-55	Rock elevation
	56-60	Rock offset
1R	61-65	Right Rock elevation #1
	66-70	Right Rock offset #1
2R	71-75	Right Rock elevation #2
	76-80	Right Rock elevation #2

The following instructions are used in preparing a design sheet. The county number is placed in the column headed (CO. 1-3). All digits on a card must be filled with a character. Zeros are placed in all blank fields. It is not necessary to repeat duplicated numbers. Ditto marks or arrows may be used in preparing design sheets to indicate repetition. The route number is placed in the column headed (RTE. 4-6), district number in the column headed (DIS. 7). The column headed (ROCK 8) is used to code for rock slopes. The rock codes are explained in the following table:

Code 3 - Normal section no rock
4 - Rock bench Rt. and Lt.
5 - Rock do not bench Rt. or Lt.
6 - Rock no bench Lt. bench Rt.
7 - Rock no bench Rt. bench Lt.

No error results from giving a rock code of (4) when the rock line lies below the template applied. In this case the proper Class A slopes are applied and cut excavation is calculated as Class A excavation rather than as rock excavation. No error results from indicating rock codes 4, 5, 6 or 7 when the section is a fill section. The computer tests for cut or fill at each roadbed point and applies proper slopes and ditches. The computer also tests the shoulders for greater, or less than ten foot slope conditions. Error does result if the rock line is placed above the ground line. This warning is not absurd in that the rock line and ground line are coded into the computer separately. The rock line is extended by the computer a hundred feet right and left of the last rock point given. If care is not taken in placing the rock line, the last rock point may be extended across the ground line. An additional rock point directing the rock line downward can correct this. Every effort should be taken to insure that the ground line given extends beyond the limits of the template applied.

When the backslopes of a section extend beyond the ground line, the computer uses a vertical slope to produce an intersection with the ground line and signals an error by placing a negative sign in the Median code in column (24) on the output cards.

The amount of superelevation is entered in column Super 9-11. It is a three digit figure giving the super in feet per foot. A super rate of .08 is coded as 080. A left turn is considered as a negative value and a right turn as a positive value. The computer program takes the distance each roadbed point is from the profile grade point and multiplies this difference times the super rate. Super transitions are prepared on graph paper. Intermediate values of super are interpolated. The station numbers are placed under the column labeled Station 12-17. It is a 6 digit number. A station of 79+50 is shown as 007950. All stations are given to the nearest foot.

The profile grade elevation is entered in the columns headed (Pav't. Elev. 18-23).

Column 24 is used to select one of two templates to apply at a section. A code of (0) applies the roadbed section with X-ordinates in memory location 500 to 515 and Y-ordinates of 550 to 565. A code (1) applies the roadbed template points in locations 600 to 615 and from 650 to 665.

A (2) in column 24 is used to indicate a transitioned section from one type of section to another. The column headed (Pav't. Mod. 25-27) enters the rate of pavement widening. A value of 2.00 feet is entered as 200. The column headed (Shldr. Mod. 28-30) enters the rate of shoulder modification.

The rock line is entered from the design sheet columns (31-80). It consists of five rock shots each consisting of X and Y-ordinates. The X-ordinates are taken from a X axis a thousand feet left of the survey centerline. The Y-ordinates are given in terms of absolute elevations. A sample design is on page 3. A minimum of three points is required to establish a rock line. The center shot given must be at the survey centerline. End shots are given to extend the rock line beyond slope limits. A maximum of five rock shots per section is available. The rock line cannot be shown above the ground line. It can be given as coincident with the ground line at any point needed. Rock shots are developed from core drill records and geology maps.

To better understand the inner workings of the program a general description follows:

The Missouri earthwork cut and fill program is divided into 9 blocks of computations. The first two blocks are used to check station sequence and convert rod readings to absolute elevations and store general information as entered. Block 3 computes template points and corrects for superelevation and variable section width. Block 4 makes slope decisions. It determines whether the section is cut or fill; it determines whether slopes are greater or less than 10 feet; and calculates the slope stake points. Block 5 computes the end area for each

section. Block 6 stores template points and slope intercepts for punch out. Block 7 is used to make rock decisions and to correct template area for rock areas. Block 8 calculates the volume between sections, the sum volumes to present location, and balanced volumes. Block 9 stores template points and yardage quantities for punch out. See pages 21 to 46 for flow diagrams.

DESCRIPTION OF SPECIAL EARTHWORK CONDITIONS HANDLED BY COMPUTER

The Missouri program for the design of earthwork computations takes into account the following conditions:

1. End area calculations including subgrade trench, and variable material layers.

2. Any standard changes in cross-section design, such as superelevation, ditches, and changes in backslope.

3. It is flexible enough to permit the designer to make changes in backslopes and dimensions as desired.

4. A complete sequence of operations not requiring total re-entry and recomputation of data for design changes.

5. Different programs for dual lane and single lane design can be handled.

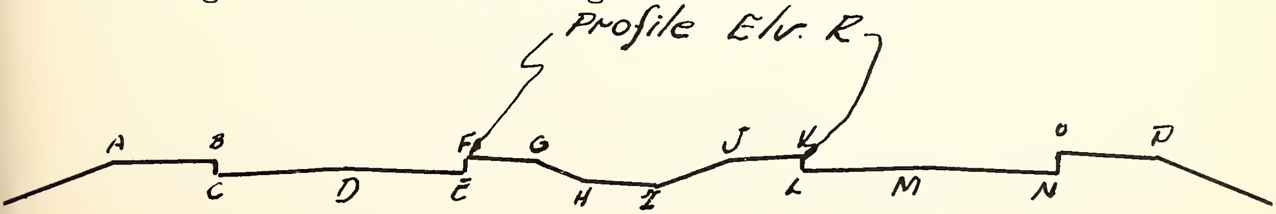
6. It permits changes, such as grade changes not requiring new input of survey data to be made rapidly.

7. It keeps any changes to present design methods to a bare minimum, that is, survey notes taken in exact method presently used. Rod readings are converted to x-y-z co-ordinates by the computer.

8. The developed program is not complicated beyond the skill of designers to enter into the computer.

PROGRAM SCHEME FOR EARTHWORK COMPUTATIONS

STEP I. <u>The Standard Cross Section Details</u> between shoulder points are written into the memory of the electronic computer for single or dual lane design.



A transverse profile is computed following the line A-B-C----. Horizontal co-ordinates are given for these points. Vertical co-ordinates are expressed in relation to the profile elevation. This is to facilitate running a continuous grade and obtaining templates without figuring individual ordinates.

Example:	Elv. R - Sh. slope - 2.0'	= Elv. H & I
	Elv. R	= Elv. B,F,K,O
	Elv. R - Depth	= Elv. C,E,L,N
	Elv. R - Depth + Crown	= Elv. D,M
	Elv. R - Sh. Slope, Depth	= Elv. A,G,J,P
		Height of Base + Pav't. Thickness

This roadbed information is entered in order from left to right. Elevations between shoulder points are expressed in hundredths of a foot (i.e. 0.00'). See page 159.

STEP II. Superelevation Adjustment

Adjustments to the vertical ordinates for superelevated sections are written into the memory of the computer. Horizontal co-ordinates are taken from Step No. I. Vertical co-ordinates are expressed in terms of the profile grade with separate memories for Super Rt. and Lt. The correction formulas for super are as follows:

Elv. A $= R \pm$ (S.E.) (R_1-A)

Elv. B $= R \pm$ (S.E.) (R_1-B)

Elv. C = B - Depth of Slab and Base

Elv. D $= R \pm$ (S.E.) (R_1-C)

Elv. E $= R \mp$ (R_1-E) (S.E.) - Depth

Elv. F $= R \mp$ (S.E.) (R_1-F)

Elv. G $= R \mp$ (S.E.) (R_1-G)

Elv. H = G-2'

Elv. I = H

Elv. J $= R \pm$ (S.E.) (R_2-J)

Elv. K $= R \pm$ (S.E.) (R_2-K)

Elv. L = K - Depth

Elv. M $= R \mp$ (S.E.) (R_2-M)

Elv. N $= R \mp$ (S.E.) (R_2-N)

Elv. O = N + Depth

Elv. P $= R \mp 10$ (S.E.) (R_2-P)

Values of the super are punched on the input cards along with the beginning and ending points of maximum super. Intermediate values of super are scaled from charts of super transitions. This job will be later programmed for automation at the time of centerline elevation calculations.

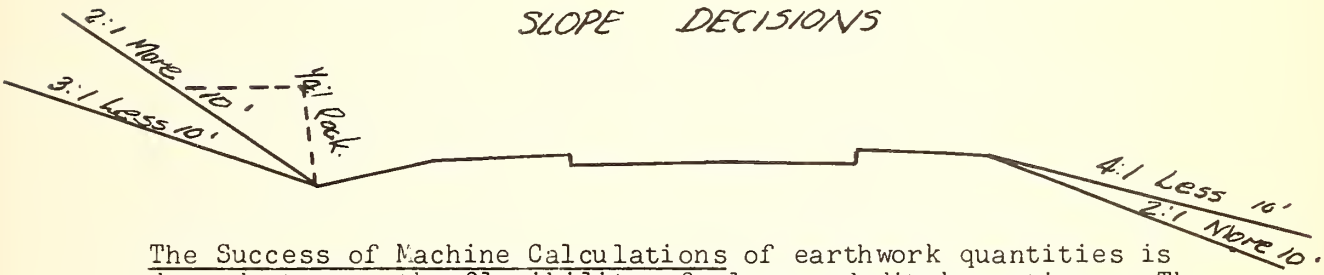
STEP III. Slope and Ditch Routine. This routine has been standardized for all highway departments. The computer makes the following routine decisions:

1. Whether to cut a ditch or not (depending on whether cut or fill section).

2. Which rate of slope to be used (depending on height, or depth of section).

3. Whether to use rock slope (depending on height of rock).

SLOPE DECISIONS



The Success of Machine Calculations of earthwork quantities is dependent upon the flexibility of slope and ditch routines. The following items are easily changed at each cross-section, if necessary, at time of data input.

1. Depth of ditch

2. Rates of slopes for cut or fill

3. Shrinkage and swell factors

STEP IV. Centerline Profile Elevation Input. The information required for centerline profile elevation input is as follows:

1. Gradient (expressed as per cent of grade)

2. Elevation and station of points of intersection (PI)

3. Length of vertical curves

4. The stations of ending and beginning maximum super elevations are given along with length of transition.

Elevations to be computed to 0.00'; gradients usually computed to 0.000%, and rarely 0.0000%.

STEP V. Cross-Section Data Input. This is the largest data input state. The station of each cross-section is punched into cards. Station numbers and height of instruments are provided. Rod readings and their centerline offsets are punched onto the cards. Rod readings are given as 0.0'; offsets to the nearest foot.

In areas of combined Class C and Class A excavation, the elevation of rock at each cross-section centerline is given. Two additional rock elevations and their centerline offsets are given. Rock elevations are entered similar to the ground line by station numbers and centerline offsets. Absolute elevations are given to the rock rather than rod readings.

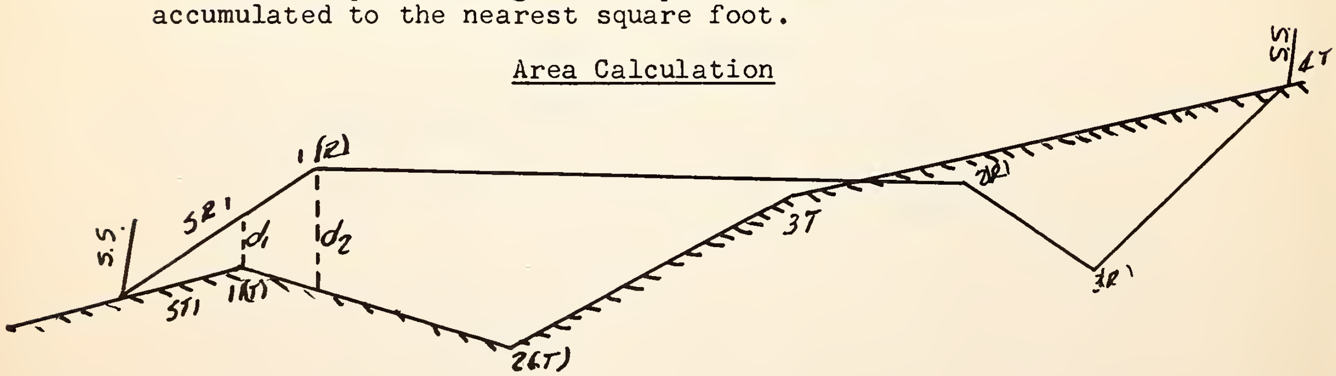
STEP VI. Computer Processing.

1. Centerline elevations are calculated from the input data given. Rod readings are computed to absolute elevations from their given HI's. This is to place computer calculations on an X, Y, and Z co-ordinate system.

2. Slope Stake Point Search. With the terrain cross-sections reduced to absolute elevations, the slope stake search begins. Slope stake points are recorded to the nearest 0.0' in elevation and to the nearest 0.0' offset. Slope decisions are made in Block 4. The program is first initialized in Block 4 with the following assumptions: No rock, no error, no ground line intercepts, left side of section, cut section, and no ten foot intersection. Thus the program first selects cut slopes and tests for left or right side. It then checks the elevation of the ditch bottom. The program uses this elevation to test for cut or fill. If the ditch point lies below the ground line, cut slopes are used; if the ditch point lies above ground, fill slopes are applied. The program selects the flatter slope for trial and calculates the slope intercept. The slope intercept is compared to the ditch or shoulder elevation. If the difference is greater than 10 feet a steeper slope is tried. Then the section is tested for rock cycle and if this condition exists, rock slopes are applied. This sequence of operations is then repeated for the right side and the program proceeds to the end area calculations. The formulas used in making the above calculations are indicated on page 18 along with a list of subscripts and abbreviations on page 16-17.

3. Computation of End Areas. End areas of cut and fill are computed using the trapezoidal method. End areas are accumulated to the nearest square foot.

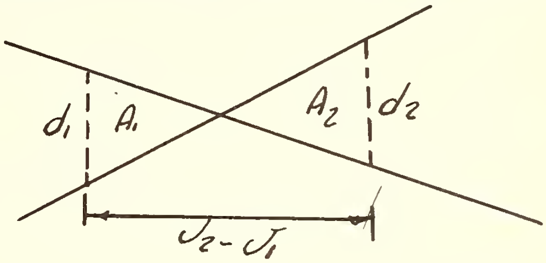
Area Calculation



Area calculations are performed in the Missouri Cut & Fill Program by dividing the cross-section into a series of trapezoids. The computer starts at the left slope stake point and selects the first terrain point and roadbed point to the right (1T, 1R). These points are compared for distance and the nearer is chosen (1T). The slope of the roadbed is then used to complete the elevation opposite the closer point. The difference between these points gives the distance d_1. The left slope stake point is assumed as a zero trapezoid side and the area is computed using ½ product of x and d_1. The sign of d_1 is checked for cut or fill storage. The computer then selects the next nearest point and computes d_2. After this d_1 and d_2 are used to compute the area of the second trapezoid. The formula used is $A = d_1 + d_2\ (.5)\ (J_2-J_1)$. The area computation then proceeds across the section. If the ground line crosses the roadbed line, the areas encountered are pro-rated by the following triangular area formulas.

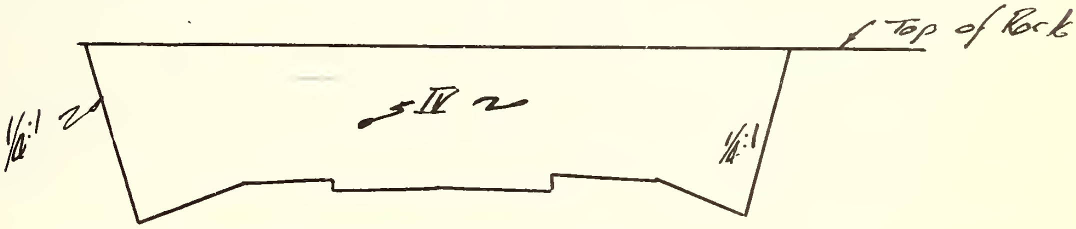
$$A_1 = \frac{J_2-J_1\,(.5)(d_1)^2}{|d_1|+|d_2|}$$

$$A_2 = \frac{J_2-J_1\,(.5)(d_2)^2}{|d_1|+|d_2|}$$

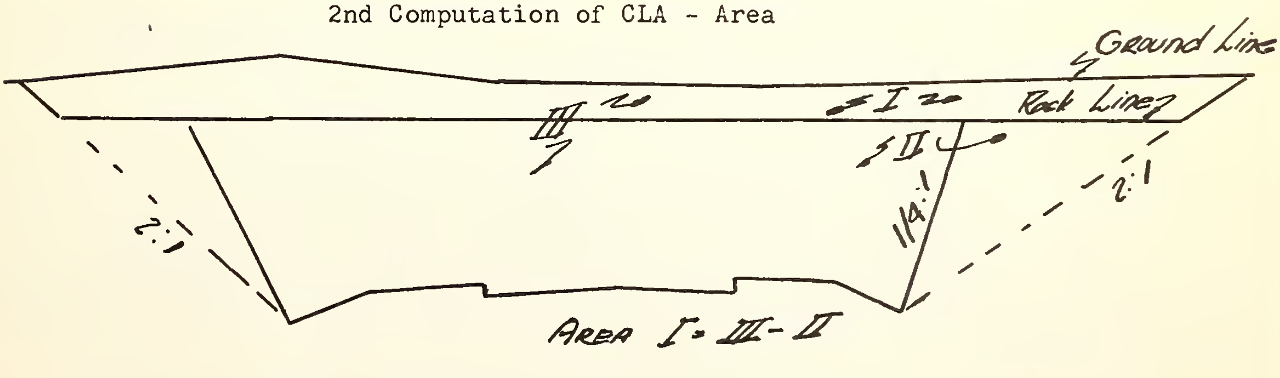


The top of rock is programmed into the computer by the same method as ground elevations. The intercept points of the rock slope give the top of the rock bench and limits of rock excavation. The area above the rock on the Class A excavation is equivalent to the difference between the area of the total section III and the part section II below.

EXAMPLE: 1st Computation of CLC - Area



2nd Computation of CLA - Area



AREA I = III - II

4. Computations Volume. The volumes of cut and fill are computed by using the average end areas of adjacent cross-sections and the distances between them. The answers are given to the nearest cubic yard of cut and fill.

5. Accumulation of Cut and Fill. As computations progress, the accumulations of cut and fill volumes are carried forward.

6. Accumulated Difference of Cut and Fill. A tabulation of accumulated differences between cut and fill volumes is carried forward. This mass diagram indicates the places for balance points, borrow excavations, and overhaul computations. The ordinates to the mass diagram are computed using the following formulas:

$$\frac{\text{CLA}}{\text{SHRINK}} + \text{Swell (CLC)} = \text{Fill}$$

The equation is now multiplied through by the shrink to apply the shrinkage factor to the fill.

CLA + (Shrink) (Swell) CLC = Fill (Shrink)
Shifting gives
CLA + (Shrink) (Swell) CLC - (Shrink) Fill = Balance

STEP VII. Computer Print Out

The computer can be programmed to print out any information entered, or computed. This includes stations, center-line elevations, grade percentages, slope stake offsets and elevations, shoulder elevations, end areas, volumes, and running totals of cut and fill and mass diagram ordinates. The Designer can use this information to plot any cross-sections needed for inclusion in final plans. Cross-sections are plotted at culverts, special design points, and at any critical point desired. Many repetitious cross-sections can be eliminated.

The widening for pavements and shoulders is accomplished by indicating the amount of the widening on the design sheet columns labeled shoulder, or pavement modification .

The Missouri program is set up to handle special ditches with variable widths and variable intervening berms. The designers codes this information into the machine by giving the identifying information on design sheet I. a negative sign, this causes the computer to read another card containing the modifying information for special ditches. The design sheets for this information are on pages 16-17.

A brief description of the application of this information follows.

Special ditches can be designed and entered into the computer only after a primary run. The first run provides essential information about the location of cut cross-sections, the location of fill cross-sections, the elevations of standard ditch bottoms, the elevations and offsets of slope stake points, fill limits by centerline offset, elevations at fill toes, roadway shoulder elevations and offsets. The proper study and utilization of this information will provide ditch design data with a minimum of cross-section plotting.

In approximately 75% of the cut sections the standard ditch section as applied by the computer will be correct. The only modification required on these sections is widening to handle excessive drainage discharges. In the remaining 25% of the cut sections the largest number of design modifications will be to correct for maximum allowable ditch grades as determined by soil conditions or to provide minimum grade for drainage.

In fill areas it is necessary to provide special ditches for drainage purposes and to protect fill toes. Side ditches at fill sections are separated from the roadbed proper by a fill berm.

On dual lane highways the median ditch requires an elevation adjustment in flat areas to insure drainage. Each of the above drainage ditch types will be considered individually in this letter. This design letter is a guide to designing these special ditches by the electronic computer. The methods shown can be improved and implemented for additional conditions as needed. The proper improvements to these methods can be determined only by use and application. The methods as outlined indicate a detailed and thorough method for designing special ditches. The drainage ditch modifications are divided into three classifications for clarification. The following sheets define the classifications and show how to modify roadway slopes, introduce corrected ditch widths and elevations, and provide fill berms for complete ditch design. Following these short explanations is a sample design problem showing where and when the modifications are needed and how they can be applied.

CLASS A DRAINAGE DITCHES

The first classification of drainage ditches is used for ditch widening and ditch grade changes in cut sections. This type of side ditch normally only needs to be modified in width to handle extra drainage. Occasionally, however, it will be necessary to use ditch grades that are different from the centerline profile grade. The designer codes ditch grade and widening corrections on Design Sheet II. (See illustrated example and sample Design Sheet II, P.16-17). The designer indicates to the computer to provide standard shoulder inslopes by placing zeros in the column labeled "Shoulder Inslope Correction". The designer indicates to the computer to apply standard backslopes by placing zeros in the column labeled "Backslope from Special Ditch", on Design Sheet II. The designer indicates to the computer to select a special backslope or inslope by giving the tangent of the desired slope in

the appropriate column. The designer plots on profile paper the ditch grade as to station and elevation from the initial run on the computer. The designer determines if a revised ditch grade is necessary and plots the corrected ditch grade with straight edge or french curve on the profile sheet. The new ditch profile should lie below the old profile and the new ditch elevations are taken from this drainage profile and listed on the design sheets.

CLASS B DRAINAGE DITCHES

This classification of ditches is used for special flat bottom side ditches at the bottom of fill slopes. The ditches in this case are offset with a berm at the toe of the fill slopes. The slope stake elevations and offsets from the first run computer tabulation sheets locates for the designer the toes of fill sections. The fill toe elevation provides the elevation to be used by the designer for the berm. The berm must be adjusted to produce a continuous smooth line at holes and humps in the profile. Partial cross-sections to show special ditches are plotted as needed to aid in the design of the special ditches and berms. Design Sheet III is used in preparing the computer input information for Class B ditches. Design Sheet III is used for Class B ditches to the left and right of roadbed centerline. (See illustrative drawings and sample design sheets, pages 18, 19 and 20). Design Sheet III contains columns of input information controlling ditch depth, ditch elevation, ditch width, shoulder inslope, ditch back-slope and ditch offset control. The designer, by using various ditch widths, elevations, and depths can obtain any desired shape of berm and drainage ditch needed. The elevation of the ditch berm is determined by the designer in giving the ditch depth and the elevation of the ditch bottom. The berm width is determined by the designer from the fill height and soil conditions at a given section.

The berm width plus the fill toe offset plus the ditch depth times slope locates the minimum ditch offset control to be used. (See drawings).

CLASS C DRAINAGE DITCHES

This ditch classification is used in the design and control of median ditch depths. The illustrative drawing for Class C ditches on page 10 is for a ditch section on a 60 feet median using the new standard 1 AD I-60-1. A maximum median ditch depth of 4'-4½" is permissible on this section. In order to obtain drainage on flat grades the designer sets the elevation at the beginning of the ditch grade to the minimum ditch depth of 2'-10½" below profile grade. The designer then gradually lowers this elevation until the maximum median depth is reached. Special columns are given on Design Sheets II and III for median ditch corrections. The computer automatically decreases the median ditch elevation by the amount indicated in this column.

SLOPE ROUNDING, BACKSLOPE PROTECTION DIKES, AND UNDERGRADING

The small amount of yardage involved in providing dikes and interception ditches for protecting backslopes permits the estimation of the earthwork quantities by multiplying a constant yardage volume per station by the station length.

Slope rounding and any required undergrading for fireclay, or other unsuitable material can be handled in a similar manner.

The designer may estimate his right of way requirements for small dikes and interception ditches at each cross-section by adding the dike and interception ditch width to the backslope stake offset distance given on the computer tabulation sheets. Protective dikes and ditches of this type are to follow the natural grade of the ground and are not to involve excessive yardage quantities.

CROSS-SECTION SHEETS

The electronic computation of cross-section end areas, yardage quantities, slope stake points, and shoulder points eliminates the need of plotting cross-sections that are repetitious of standard details. Typical cross-sections repetitious in type are to be plotted at five hundred foot intervals only. Special cross-sections needed to indicate special design details are to be plotted at culverts, sideroads, interchanges, and other similar features. Partial sections to show details of special ditch design can be plotted between typical sections. Construction notes at sideroads, culverts, interchanges, and etc. are placed on the special cross-section sheets indicated above. All construction notes normally placed on regular cross-section sheets shall be placed on plan-profile sheets. Special ditch grades are to be shown on plan sheet profiles. The beginning and end of special ditches along with plan location and width are to be given on plan views for the Resident Engineer in staking out the work.

The computer tabulation sheets are to be attached at the back of the special cross-sections and become an integral part of them.

Culvert sections only are to be forwarded to the main office. The District office is to retain the remaining sections and tabulation sheets to conform with present practice. The contractors, or construction men can plot any section required from the computer tabulation sheets giving roadbed co-ordinates.

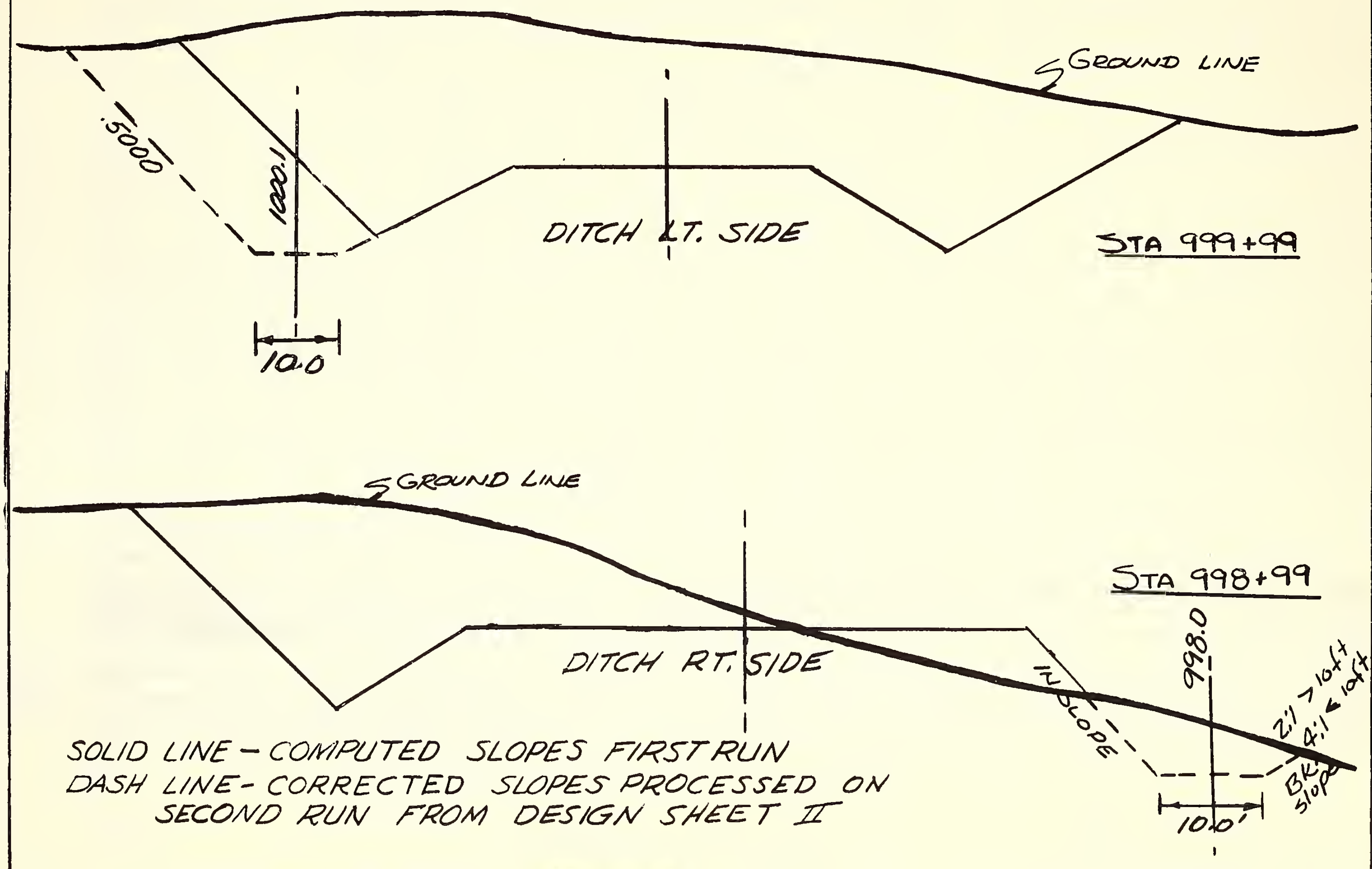
These pages have been a general description of the earthwork program used in Missouri for variable material earthwork calculation. Many improvements and additions are still needed and required for a complete design program.

DESIGN SHEET II
SPECIAL DITCH
CUT SIDE DITCHES

CO. ______________
RTE. ______________
PROJ.

12-17	18-23	36-40	41-45	28-30	46-50	66-70	71-75	56-60	76-80
	LEFT SIDE				RIGHT SIDE				
STATION NUMBER	DITCH PROFILE GRADE ELEVATION	SHOULDER INSLOPE CORRECTION	BACKSLOPE FROM SPECIAL DITCH	DITCH WIDTH	DITCH PROFILE GRADE ELEVATION	SHOULDER INSLOPE CORRECTION	BACKSLOPE FROM SPECIAL DITCH	DITCH WIDTH	MED DITCH ELV
998 99	0			—	0998.0	0000	0000	010.0	000
999 99	1000.1	0000	5000	010.0	0			—	—

TYPICAL APPLICATION
DESIGN SHEET II
CLASS A DITCHES
CUT SECTIONS
SPECIAL DITCHES LT SIDE OR RT SIDE



DESIGN SHEET III

FILL SIDE DITCH DESIGN

CO ____________ 1-3
RTE ____________ 4-6
DIS ____________ 7

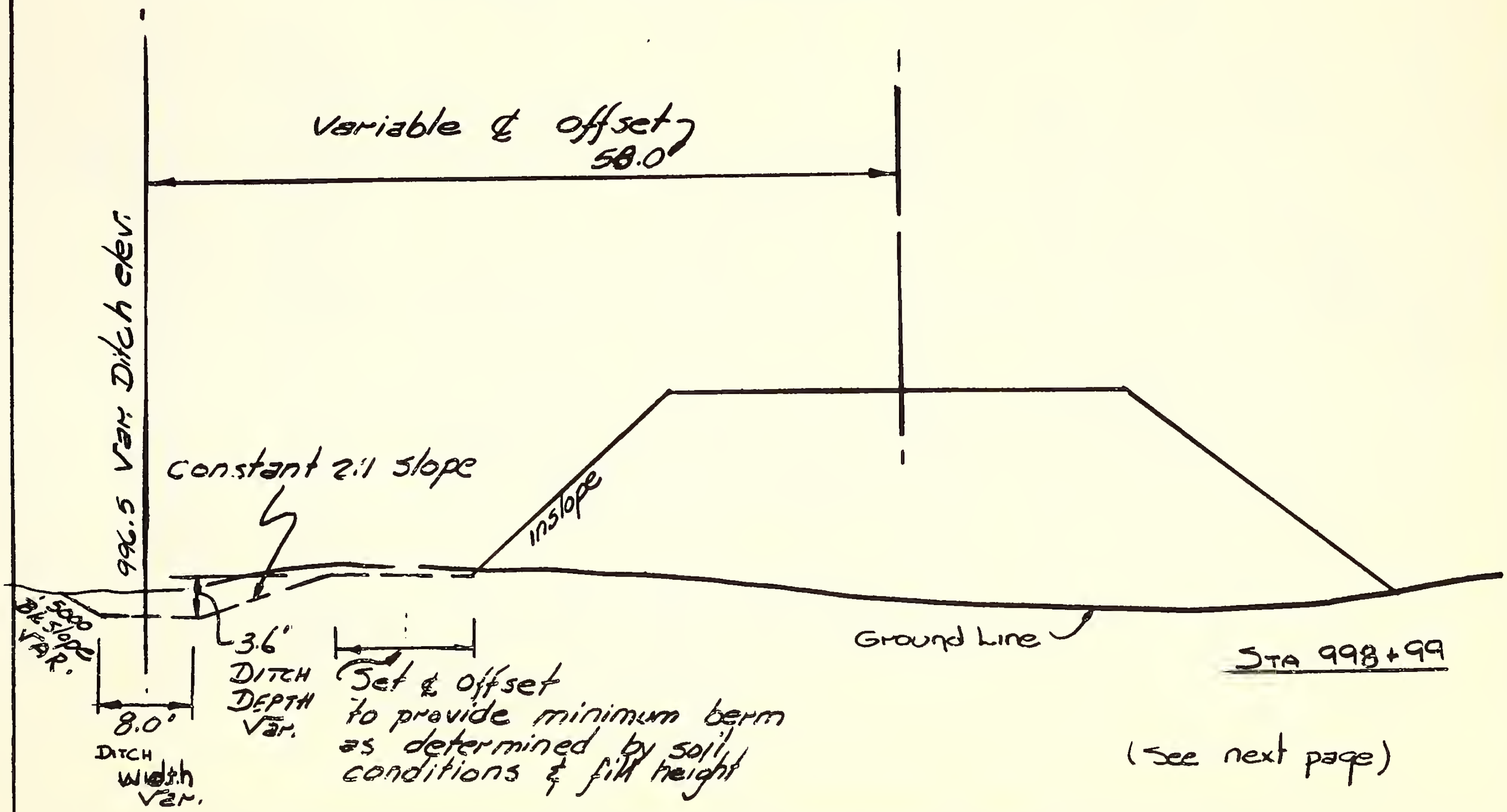
LT. SIDE | RT SIDE

12-17 STATION NUMBER	18-23 DITCH ELV	24-27 ℄ OFFSET	28-30 DITCH WIDTH	31-35 DITCH DEPTH	36-40 INSLOPE	41-45 BACK-SLOPE	46-50 DITCH ELV	51-55 ℄ OFFSET	56-60 DITCH WIDTH	61-65 DITCH DEPTH	66-70 INSLOPE	71-75 BACK SLOPE	76-80 MED DITCH ELV
998 99	0996.5	058.0	08.0	03.6	0000	0000	0						→
999 99	—					→	0798.0	051.0	10-0	02.0	00.00	0000	0000

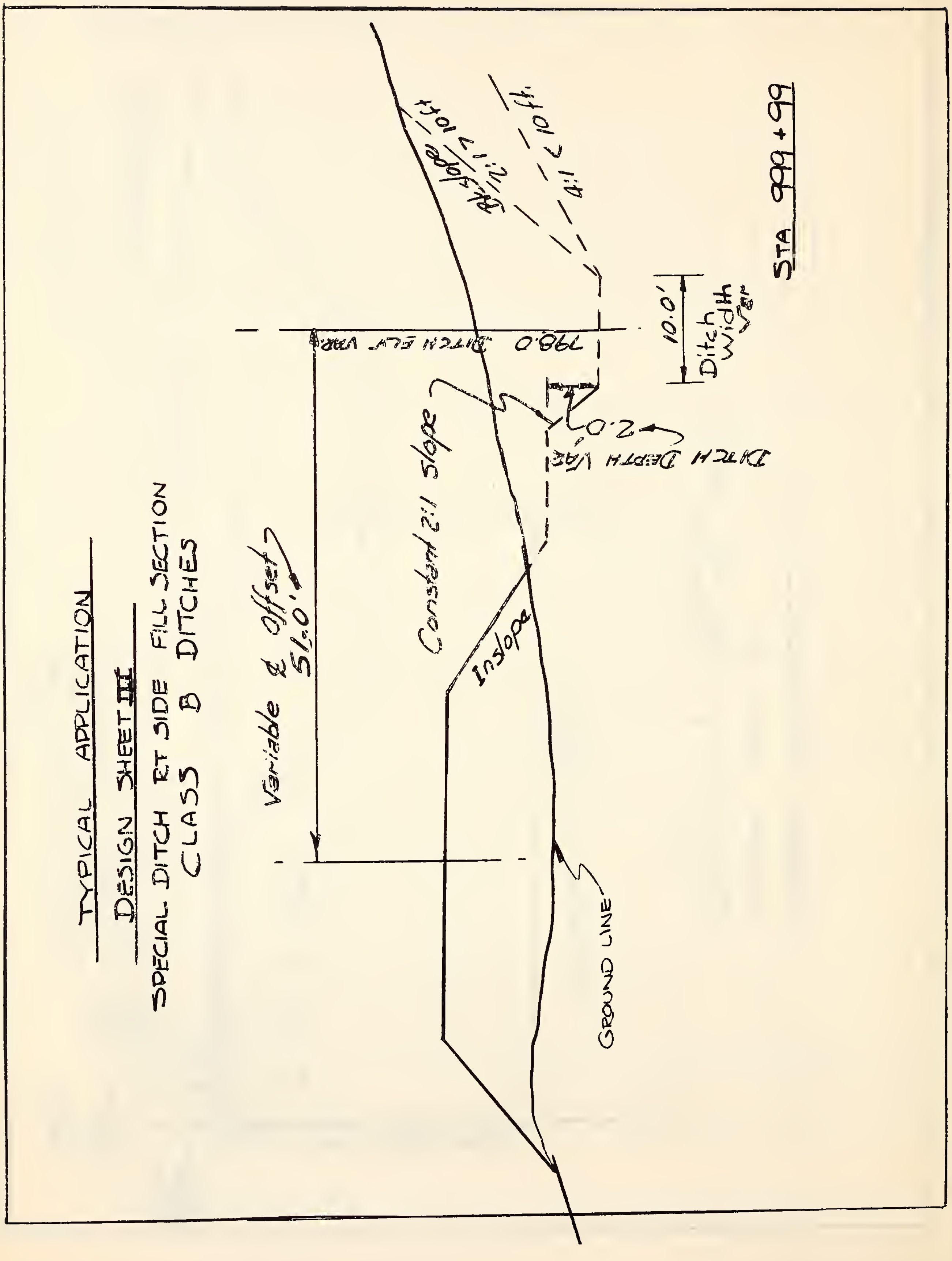
TYPICAL APPLICATION

DESIGN SHEET III

SPECIAL DITCH LT. SIDE FILL SECTION
CLASS B DITCHES



(See next page)


TYPICAL APPLICATION
DESIGN SHEET III
SPECIAL DITCH RT SIDE FILL SECTION
CLASS B DITCHES
Variable ℄ offset
51.0'
Constant 2:1 Slope
Inslope
798.0 DITCH ELV VAR.
2.0'
DITCH DEPTH VAR.
10.0'
Ditch Width Var.
Backslope 2:1 < 10 ft
4:1 < 10 ft.
STA 999+99
GROUND LINE

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

L. E. Davidson
Illinois Division of Highways

THE EARTHWORD PROBLEM BY THE ILLINOIS DIVISION OF HIGHWAYS

The Bureau of Research and Planning of the Illinois Division of Highways has developed a program for the Bendix G-15A electronic computer for the determination of highway cut and fill quantities and other essential earthwork design data. The program was planned to handle the Illinois standard design roadway cross sections which have a trenched subgrade, two cut back slopes and three fill side slopes. In the planning stage it was decided that, in its initial state, such a program should be:

1. Applicable to the earthwork design for a two-lane highway using any of the State's several standard design roadway cross sections,

2. Flexible to the extent that it could be easily altered or modified so that it would compute the earthwork quantities for dual highways, widening and resurfacing jobs and borrow pits, and

3. Able to produce the desired results in one computer operation without reentry of data.

In order to meet these conditions the program was divided into a series of sequential subroutines, each of which would compute certain essential data to be used in the subsequent subroutine, and any of which could be modified or replaced without affecting the operation of the remaining part of the program.

All computer input is punched on paper tapes prior to the solution of the problem. These tapes consist of the following:

(A) The program tape which is the series of instructions and formulas that the computer follows in the solution of the problem.

(B) The roadway template tape on which are recorded not only the standard template dimensions to be used, but also the locations and numerical values of any deviations from standard template dimensions which may be desired.

(C) The grade line data tape which contains the beginning station and its pavement centerline elevation, the successive tangent grades and the locations and lengths of successive vertical curves from beginning to end of the project.

(D) The ground cross section tape which contains the station number, height of instrument and rod readings and offsets copied directly from the survey notebooks. It also contains the rate and direction of superelevation for those cross sections which are within the limits of horizontal curves, as well as specific code numbers which cause the program to make adjustments for equation of stations and for earthwork volume omissions for bridges or any other scheduled gaps within the limits of the project.

For solution of an earthwork problem tapes "A," "B," and "C" as above described are loaded into the computer's memory and tape "D" is placed on the computer for read-in of cross sections one at a time as computations advance station-by-station through the project. Operation of the program is automatic and proceeds through the subroutines as follows:

(1) Crown Elevation Subroutine

Crown elevations are determined for each cross section station by first computing the tangent elevation for that station and then, if the cross section is within the limits of a vertical curve, adding or subtracting, as the case may be, the tangent offset to the vertical curve at that point.

(2) Template Simulation Subroutine

This subroutine computes and stores for later use in the program the offsets from centerline and the elevations of up to six template points for each half of the highway. The computations are made from template dimension data previously stored and the crown elevation as determined in the proceeding subroutine.

(3) Slope Selection Subroutine

This subroutine in effect superimposes the roadway template on the ground cross section, and from the difference in elevation between the template and ground lines selects which of two cut backslopes or three fill slopes should be used. It next computes the offset from centerline and the elevation for the intersection of the selected template slope and the ground line. First, the slope stake coordinates for the left side of the roadway are determined, then the ones for the right side. In case

of very uneven ground where more than one such intersection could occur, the one farthest from centerline is selected. This is done in order to obtain as smooth a roadway between right-of-way lines as is possible.

(4) Area Computation Subroutine

End areas of cut and/or fill are calculated as the summation of areas of a series of trapezoids and triangles between successive break points on the template and ground starting with the slope stake coordinates and advancing to the centerline, first for the left half then the right half of roadway.

(5) Shrinkage Factor Subroutine

The practice in Illinois is to use a variable shrinkage factor, which, when reduced to a unit length of roadway of one station (100 feet), is a function of the end area of fill. A formula for shrinkage factor has been derived and inserted in the program which automatically adjusts the end area of fill for each cross section to compensate for shrinkage. This formula is based on data obtained from an examination of shrinkage behavior on highway construction projects throughout the State over a period of many years. Although there is considerable variation in the actual percent of shrinkage used for various parts of the State, the formula can be adjusted, by the insertion of one of three values for each of two variables, to give the shrinkage factor which experience indicates should be used for the particular part of the State in which the project is located.

(6) Volume Computation Subroutine

The calculation of cu. yds. of cut or fill or adjusted (for shrinkage) fill between successive cross sections consist of multiplying the distance between the two cross sections by the average sum of the end areas of cut or fill or adjusted fill (as the case may be) for the two cross sections and reducing this volume which is in cu. ft. to cu. yds.

The printed output from the computer gives the following information for each cross section station:

The station number and its crown elevation

The left slope stake offset and elevation and the selected cut backslope or fill side slope ratio

The same for the right slope stake

The end areas of cut and/or fill for each cross section

The cu. yds. of cut and/or fill and fill adjusted for shrinkage between successive cross sections

The accumulated cu. yds. of cut and/or fill progressively from beginning to end of the project

The accumulated net difference of cut and adjusted fill progressively from beginning to end of the project.

This last item gives the ordinates for plotting a mass diagram, and also indicates the amount of excess material to be disposed, or the amount of borrow to be acquired.

As a second stage in development, the program as above outlined has recently been modified so that it will compute the earthwork quantities for a dual highway with a uniform width median and with vertically parallel (but not necessarily at the same elevation) grade lines, and for which superelevation is applied by rotating the pavements about their median edge. This program was prepared by duplicating the tape for the original program with the exception of the template simulation subroutine, for which was substituted a new template simulation subroutine that computes and stores the coordinates for eleven critical template points on each side of centerline.

Other modifications of the program to extend its usefulness will be made as time permits.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Philip King
King and Gavaris

THE USE OF ELECTRONIC COMPUTATION TO EXPEDITE HIGHWAY LOCATION AND DESIGN

This paper will discuss the use of an electronic computer as a tool to expedite highway location and design. We reiterate and emphasize the word "tool," since it is our studied opinion that an electronic computer is not a substitute for education, experience and judgment. This may sound like heresy in the world of electronic impulses. However, there are primary considerations in the location and design of a highway project which cannot be programed for search and evaluation by an electronic computer.

A balanced earthwork job is not necessarily the best practical highway. Physical features such as badly drained areas, unsuitable material, the areas of available topsoil for stockpiling, disintegrated rock and a large number of drainage conditions are not readily apparent until examined thoroughly by a competent engineer, skilled in the needs of highway design and construction.

This paper will correlate the programs developed for a Royal McBee LGP-30 digital electronic computer as applied to a portion of the new Interstate Highway System presently under design for the New York State Department of Public Works. This project complies with the latest interstate standards of the Bureau of Public Roads and the New York State Department of Public Works.

In the interest of clarity we will outline briefly the use of the electronic computer programs in terms of the chronological progression of a highway location and design project.

The first program for computer use is a traverse closure program. It is used to balance and close the angles and distances of the ground control points for the photogrammetric mapping. Transit rule and compass rule programs were prepared. Slide #1 indicates the printout of a typical program:

Description of Slide #1

Thirty-eight legs of a completed closure problem of a portion of the work are shown. The original data consisted of the coordinates and station of the point of beginning, the measured angles and distances of the intermediate points and the coordinate of the point of ending. Since the angles are measured with an accurate transit, and are turned a minimum of six times a greater accuracy can be obtained by balancing the distances which have been taped, which is transit rule, then balancing the angles and distances under compass rule. It is readily apparent that work for ground control for subsequent mapping can proceed quickly.

This balanced traverse line becomes a random line from which future stakeouts can readily be made. The intermediate points are monumented, referenced and tied so that they may be picked up in the field at a later date. After the photogrammetric mapping is completed a centerline and profile for the project is studied and determined. An acceptable line and grade having been obtained the calculation of the alignment and the development of the profile details are analyzed on the electronic computer. To place the centerline in the field, programs have been developed referencing the new proposed centerline with the random line previously discussed. One of the programs used in the computer for this purpose is shown on Slide #2.

Description of Slide #2

In this instance you will notice that the proposed centerline crosses the random line. The four angles at the intersection are computed by the machine, the necessary distances, coordinates, and bearings are shown in the order indicated. The output is printed on transparent material, blueprinted and copies sent to the field. This insures a rapid progression of accurate work. Programs have been developed where the random line and the centerline do not cross. These programs will be discussed in another paper.

We have found this procedure of monumenting a centerline at an early stage of design quite helpful. The right-of-way acquisition maps contain the proposed centerline and each property is located in terms of stations and offsets from this line. A program for the calculation of bearings and distances of each taking is under study in this office at present.

The development of the profile in terms of 50-foot stations or at such lesser intervals as may be required by rougher terrain has been programed for the computer. Slide #3 shows the program.

Description of Slide #3

The input of this program are the stations and elevations of all P.V.I.'s from the beginning to the end of the project and the length of vertical curve at each P.V.I. The machine calculates the exact grade and prints out the data in the columnar form indicated on the slide. The reason for this form will be discussed on the slides immediately following.

The exact elevation on line is part of the imput for the cut and fill program which we now discuss.

The cut and fill program is not necessarily an earthwork program. This program can best be described as a mathematical representation of the cross section at each station. From these mathematical cross sections

the toe of slope or top of cut can be produced on the 50-foot scale plans. Drainage studies and right-of-way damage can be evaluated. Of primary importance is the fact that top of cut or toe of slope points at each station, in terms of offsets from the centerline and exact elevations, are produced by the computer during the early stages of design.

Heretofore drainage studies had to await the plotting of the cross sections where the toe of slope and top of cut lines were established and then scaled off and transferred to the plans. The savings in time involved in ascertaining the location of the toe of slope or top of cut at an early stage of design is of tremendous importance as you all realize.

In our past practice we have found that alignment and profile have to be changed to accommodate drainage which otherwise would be rather expensive. The ability to obtain correct data early reduces the number of these changes.

<u>Description of Slide #4</u>

You will note that in addition to the offsets indicated from the centerline, the elevation of the toe of slope or top of cut has been computed. This represents a search on the part of the computer as to the height of fill or depth of cut and the slope required for such depth. In fill, as an example, the slope varies from 1 on 2 maximum to 1 on 4, depending on the height of fill. Where 1 on 2 slope is used a widened shoulder to accommodate a guide rail is required. The machine selects which condition applies, searching for the height between the theoretical grade previously determined on another program and the existing grade as ascertained during survey and mapping. The slope at the mall and at the outside shoulder is indicated on the slide. It is evident, of course, how helpful this data is in the plotting of cross sections. We have found the elimination of cross sections virtually impossible, insofar as mall treatment can be obtained only by cross sections or complete contouring of the area. To produce a plan with complete contouring would not expedite a highway location and design project.

Printout of this cut and fill program is reproduced and used for the following purposes:

1. One copy is given to the cross section group for the plotting of the cross sections.

2. One copy is given to the drainage group to produce the top of cut or toe of slope lines on the plans to study drainage flow.

3. One copy is given to the field for stakeout work.

Description of Slide #5

Slide #5 represents a blank, standard earthwork sheet prepared by the New York State Department of Public Works. You will note on the slide that the columns, in order, are grade, station, elevation, etc. The reason for the output on our profile study previously described on Slide #3, and the cut and fill program on Slide #4, is to comply with the requirements of this standard sheet.

Description of Slide #6

Slide #6 is a completed earthwork sheet complying with the requirements of Slide #5. The data contained therein has been developed by the use of the computer from three different programs, namely, profile program, cut and fill program, and volume program. The areas of each cross section, were removed from the printout of a cut and fill program and attached to the profile printout. The volume between stations was calculated and the total earthwork at each 20 stations was removed from the program and again this data was attached to the original profile program.

We have found that with the rapidity of calculation obtained by using an electronic computer through most of the stages of design, refinements in alignment and grade can, and do, occur. Where these changes in alignment or profile are required new output data for the stations affected is computed and the new station data replaces the previous output. Since our earthwork program is broken down into three component programs there is no need to reproduce the entire program for final work. We believe this is fundamentally an important phase of our computer program thinking. A striking example of the use of the computer to accommodate rapid work occurred during the week of September 9, 1957.

On another section of the Interstate, presently under construction, field operations disclosed the necessity for changing the main line profile for more than one-half mile, because of poor drainage conditions. Limited soil exploration during the design stages had failed to disclose this problem. The profile on the Interstate was raised for an average of more than five feet for this one-half mile, to accommodate the prevailing condition. The contractor needed an estimate of the volumes of earthwork involved since the reduction in cut would require him to procure borrow. For a portion of the one-half mile cut was replaced by fill. This information was transferred to the New York office for analysis and study.

The information was received on the morning of the 9th of September. A program was taped for the new profile and the data fed to the computer that morning. By the evening of the 9th of September, that same day, a new grade table for the one-half mile length was completed, new offsets

for toe of slope and top of cut completed, and a new earthwork table processed, blueprinted, and sent out to the field for delivery on the 10th of September.

We have programed the geometry of bridge structures, however, since the details of this program will be described in the paper presented by my partner tomorrow, let it suffice to be seen. I would not steal his thunder.

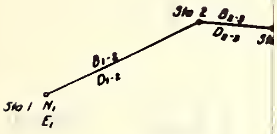
Description of Slide #7 - Geometry Program for Bridges

All station information, skew angle information, and all elevations required for critical points from crown of roadway down to and including the elevation of masonry plates are computed by the machine.

Possibly we have been very fortunate in being unable to use previously conceived programs for our own work. The type of command language and coding required for the LGP-30, although relatively simple, is different from that of the other electronic computers available. Our programs have been developed from subroutine calculations joining together to form a more ambitious program. This is diametrically opposed to the philosophy heretofore available concerning optimum use of the an electronic computer to expedite highway design and location studies. Possibly we are wrong in our concept. Approaching the use of an electronic computer from an engineering standpoint required our taking a position similar to that which we would take in the evaluation of any large project. This requires breaking a problem down to components. Study and analyze each component. When finished the analysis for a large project is completed. We believe in the future our programs may develop to more inclusive single programs than heretofore accomplished. While this study will be going on our present programing maintains full use of the computer, whereas completing an all-inclusive program, and proving it out, may leave the machine idle for a considerable length of time.

It is our studied opinion that the use of the electronic computer, as a tool, has in fact expedited highway location and design to a large degree. Thank you.

TRAVERSE CLOSUR



INPUT:

OUTPUT:

PROGRAM LENGTH:

DATA STORAGE:

SUBROUTINES USED:

COMPUTATION TIME:

Camillus to Liverpool, Traverse No. 4

4+100300'384927'814221'3560024'3560444'3562353'3562920'3553752'2660231'62402'2915454'31428'33954'210635'
1315544'280532'411306'521904'621215'674214'623247'542428'643518'715049'810106'910422'910036'910036'905851'
862729'630854'461444'461224'572009'543834'632715'813441'2694103'214827'-0000000'2+170400'8300'28067'
142305'158296'118401'104136'61210'32211'848355'577574'30650'74686'35034'276878'27613'101503'49776'
105611'87532'20872'226234'31231'44312'59880'284524'202374'271251'201362'36913'40573'179437'206924'
18473'35257'37991'89193'473648'1970152'-0000000'0+210500'1092462'060'578271'950'-0000000'0+210700'
1133986'150'599344'070'-0000000'0+290704'38'-0000000''

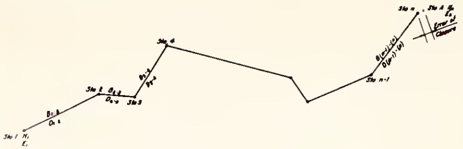
TRAVERSE CLOSURE PROBLEM

Error of Closure 00015745.

Balanced by Compass Rule

Station	Bearing	Azimuth	Distance	Coordinate N	Coordinate E
01				1092462.060	0578271.950
	N 38°-49'-17° E	038°-49'-17"	00083.003		
02				1092526.728	0578323.984
	N 81°-42'-08" E	081°-42'-08°	00280.670		
03				1092567.234	0578601.717
	N 03°-59'-37" W	356°-00'-23"	01423.140		
04				1093986.919	0578502.603
	N 03°-55'-17" W	356°-04'-43"	01583.060		
05				1095566.273	0578394.343
	N 03°-36'-08" W	356°-23'-52"	01184.085		
06				1096748.019	0578319.949
	N 03°-30'-41° W	356°-29'-19"	01041.426		
07				1097787.489	0578256.166
	N 04°-22'-09° W	355°-37'-51"	00612.139		
08				1098397.849	0578209.532
	S 86°-02'-44° W	266°-02'-44"	00322.111		
09				1098375.635	0577888.188
	N 06°-23'-59" E	006°-23'-59"	08484.074		
10				1106806.841	0578833.854
	N 68°-04'-55" W	291°-55'-05"	05775.919		
11				1108962.888	0573475.450
	N 03°-14'-26" E	003°-14'-26"	00306.519		
12				1109268.916	0573492.757
	N 03°-39'-51" E	003°-39'-51"	00746.907		
13				1110014.296	0573540.492
	N 21°-06'-29" E	021°-06'-29"	00350.360		
14				1110341.148	0573666.666
	S 48°-04'-25" E	131°-55'-35"	02768.647		
15				1108491.202	0575726.546
	N 28°-05'-24" E	028°-05'-24"	00276.144		
16				1108734.818	0575856.571
	N 41°-12'-56" E	041°-12'-56"	01015.073		
17				1109498.392	0576525.397
	N 52°-18'-53" E	052°-18'-53"	00497.776		
18				1109802.695	0576919.327
	N 62°-12'-03" E	062°-12'-03"	01056.133		
19				1110295.249	0577853.569
	N 67°-42'-01" E	067°-42'-01°	00875.334		
20				1110627.395	0578663.439
	N 62°-32'-35" E	062°-32'-35°	00208.725		
21				1110723.634	0578848.652
	N 54°-24'-16° E	054°-24'-16"	02262.408		
22				1112040.487	0580688.323
	N 64°-35'-06" E	064°-35'-06"	00312.316		
23				1112174.525	0580970.414
	N 71°-50'-36" E	071°-50'-36"	00443.125		
24				1112312.610	0581391.475
	N 81°-00'-53" E	081°-00'-53"	00598.801		
25				1112406.131	0581982.928
	S 88°-55'-51° E	091°-04'-09"	02845.214		
26				1112353.041	0584827.646
	S 88°-59'-37" E	091°-00'-23"	02023.722		
27				1112317.496	0586851.056
	S 88°-59'-37" E	091°-00'-23°	02712.485		
28				1112269.854	0589563.123
	S 89°-01'-22° E	090°-58'-38"	02013.602		
29				1112235.511	0591576.431
	N 86°-27'-16° E	086°-27'-16"	00369.128		
30				1112258.339	0591944.853
	N 63°-08'-42° E	063°-08'-42"	00405.738		
31				1112441.626	0592306.833
	N 46°-14'-33" E	046°-14'-33"	01794.438		
32				1113682.670	0593602.911
	N 46°-12'-14" E	046°-12'-14"	02069.318		
33				1115114.836	0595096.556
	N 57°-19'-57° E	057°-19'-57°	00184.735		
34				1115214.549	0595252.069
	N 54°-38'-22" E	054°-38'-22"	00352.580		
35				1115418.594	0595539.608
	N 63°-27'-03" E	063°-27'-03"	00379.918		
36				1115588.405	0595879.464
	N 81°-34'-28° E	081°-34'-28"	00891.931		
37				1115719.095	0596761.769
	S 89°-41'-16" W	269°-41'-16"	04736.516		
38				1115693.284	0592025.322
	N 21°-48'-21" E	021°-48'-21"	19702.614		
39				1133986.150	0599344.070

TRAVERSE CLOSURE



INPUT:
$B_{1-2}, B_{2-3}, B_{3-4}$ ——— $B_{(n-1)-(n)}$ Bearing or Azimuth of Consecutive Courses
$D_{1-2}, D_{2-3}, D_{3-4}$ ——— $D_{(n-1)-(n)}$ Distance of Consecutive Courses
N_1 & E_1 Coordinates of Sta. I, Starting Station
N_A & E_A Coordinates of Sta. A, End Station
(Note for closed traverse Sta. A will be identical to Sta. I)
Number of Courses of the Traverse

OUTPUT:
Error of Closure
Adjusted Bearings, Azimuths, Distances, and Coordinates
Balanced by Transit Rule or Compass Rule

PROGRAM LENGTH: 8½ Tracks

DATA STORAGE: 7 Tracks

SUBROUTINES USED:
1. Data Input
2. Data Output
3. Sine-Cosine
4. Square Root
5. Arctangent
6. Alphanumeric Output
7. Angle Input
8. Angle Output
9. Bearing Input
10. Bearing Output
11. Coordinate Input
12. Coordinate Output
13. Azimuth Computation
14. Distance Computation
15. Coordinate Computation

COMPUTATION TIME: Varies according to number of courses of the traverse. For traverse shown with 38 courses, computing time is 18½ min. approximately.

Camillus to Liverpool, Traverse No. 4

4+100300'384927'814221'5560024'5560444'5562353'5562980'5553752'2660231'62402'2915454'31428'53954'210635'
1315544'280532'411306'521904'621215'674214'623247'542428'643518'715049'810106'910422'910036'910036'905851'
862729'630854'461444'461224'572009'543834'632715'813441'2694103'214827'-0000000'2+170400'8300'28067'
142305'158296'118401'104136'61210'32211'848355'577574'30650'74686'55034'276878'27615'101505'49776'
105611'87532'20872'226234'31231'44512'59880'284524'202374'271251'201362'36913'40573'179437'206924'
18475'35257'57991'89193'473648'1970152'-0000000'0+210500'1092462'060'578271'950'-0000000'0+210700'
1133986'150'599344'070'-0000000'0+290704'38'-0000000''

TRAVERSE CLOSURE PROBLEM

Error of Closure 00015745.

Balanced by Transit Rule

Station	Bearing	Azimuth	Distance	Coordinate N	Coordinate E
01				1092462.060	0578271.950
	N 38°-49'-15" E	038°-49'-15"	00083.004		
02				1092526.729	0578323.984
	N 81°-42'-18" E	081°-42'-18"	00280.667		
03				1092567.222	0578601.715
	N 03°-59'-35" W	356°-00'-25"	01423.193		
04				1093986.960	0578502.612
	N 03°-55'-15" W	356°-04'-45"	01583.119		
05				1095566.373	0578394.363
	N 03°-36'-06" W	356°-23'-54"	01184.189		
06				1096748.163	0578319.977
	N 03°-30'-39" W	356°-29'-21"	01041.464		
07				1097787.673	0578256.201
	N 04°-22'-07" W	355°-37'-53"	00612.161		
08				1098398.056	0578209.372
	S 86°-02'-33" W	266°-02'-33"	00322.114		
09				1098375.824	0577888.226
	N 06°-23'-59" E	006°-23'-59"	08484.392		
10				1106807.344	0578833.947
	N 68°-05'-00" W	291°-55'-00"	05775.889		
11				1108963.244	0573475.496
	N 03°-14'-27" E	003°-14'-27"	00306.531		
12				1109269.285	0573492.825
	N 03°-39'-52" E	003°-39'-52"	00746.935		
13				1110014.692	0573540.365
	N 21°-06'-27" E	021°-06'-27"	00350.370		
14				1110341.554	0573666.740
	S 48°-04'-25" E	131°-55'-35"	02768.635		
15				1108491.620	0573726.614
	N 28°-05'-22" E	028°-05'-22"	00276.151		
16				1108735.244	0575856.640
	N 41°-12'-34" E	041°-12'-54"	01015.082		
17				1109498.831	0576525.465
	N 52°-18'-53" E	052°-18'-53"	00497.774		
18				1109803.133	0576919.393
	N 62°-12'-05" E	062°-12'-05"	01056.122		
19				1110295.670	0577853.631
	N 67°-42'-06" E	067°-42'-06"	00875.322		
20				1110627.794	0578663.497
	N 62°-32'-37" E	062°-32'-37"	00208.722		
21				1110724.050	0578848.709
	N 54°-24'-17" E	054°-24'-17"	02262.396		
22				1112040.873	0580688.373
	N 64°-35'-09" E	064°-35'-09"	00512.318		
23				1112174.905	0580970.462
	N 71°-50'-42" E	071°-50'-42"	00443.119		
24				1112312.976	0581391.521
	N 81°-01'-02" E	081°-01'-02"	00598.793		
25				1112406.469	0581982.971
	S 88°-55'-38" E	091°-04'-22"	02845.201		
26				1112353.204	0584827.673
	S 88°-59'-24" E	091°-00'-36"	02023.712		
27				1112317.536	0586851.071
	S 88°-59'-24" E	091°-00'-36"	02712.473		
28				1112269.727	0589563.123
	S 89°-01'-09" E	090°-58'-51"	02013.592		
29				1112235.262	0591576.420
	N 86°-27'-28" E	086°-27'-28"	00369.125		
30				1112258.068	0591944.840
	N 65°-08'-45" E	065°-08'-45"	00405.734		
31				1112441.348	0592306.818
	N 46°-14'-32" E	046°-14'-32"	01794.444		
32				1113682.404	0593602.893
	N 46°-12'-12" E	046°-12'-12"	02069.325		
33				1115114.584	0595096.534
	N 57°-19'-38" E	057°-19'-38"	00184.734		
34				1115214.296	0595252.046
	N 34°-38'-23" E	054°-38'-23"	00352.579		
35				1115418.339	0595539.584
	N 65°-27'-06" E	065°-27'-06"	00379.913		
36				1115588.145	0595879.458
	N 81°-34'-38" E	081°-34'-38"	00891.980		
37				1115718.790	0596761.738
	S 89°-41'-03" W	269°-41'-03"	04736.345		
38				1113692.685	0592025.265
	N 21°-48'-19" E	021°-48'-19"	19703.193		
39				1133986.150	0599344.070

Camillus to Liverpool, Traverse No. 4

4+100300'384927'814221'5560024'5560444'5562353'5562920'5553752'2660231'62402'2915454'51428'53954'210635'
1315544'280532'411306'521904'621215'674214'623247'542428'643518'715049'810106'910422'910036'910030'905851'
862729'630854'461444'461224'572009'543834'632715'813441'2694103'214827'-0000000'2+170400'8300'28067'
142305'158296'118401'104136'61210'32211'848355'577574'30650'74686'55034'276878'27615'101505'49776'
105611'87532'20872'226234'31231'44512'59880'284524'202374'271251'201362'36913'40573'179437'206924'
18475'35257'57991'89193'473648'1970152'-0000000'0+210500'1092462'060'578271'950'-0000000'0+210700'
1133986'150'599344'070'-0000000'0+290704'38'-0000000''

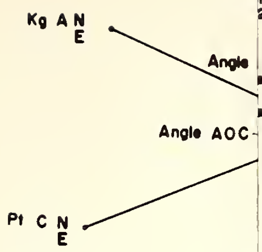
TRAVERSE CLOSURE PROBLEM

Error of Closure 00015745.

Balanced by Compass Rule

Station	Bearing	Azimuth	Distance	Coordinate N	Coordinate E
01				1092462.060	0578271.950
	N 38°-49'-17" E	038°-49'-17"	00083.003		
02				1092526.728	0578323.984
	N 81°-42'-08" E	081°-42'-08"	00280.670		
03				1092567.234	0578601.717
	N 03°-59'-37" W	356°-00'-23"	01423.140		
04				1093986.919	0578502.603
	N 03°-55'-17" W	356°-04'-43"	01583.060		
05				1095566.273	0578394.343
	N 03°-36'-08" W	356°-23'-52"	01184.085		
06				1096748.019	0578519.949
	N 03°-30'-41" W	356°-29'-19"	01041.426		
07				1097787.489	0578256.166
	N 04°-22'-09" W	355°-37'-51"	00612.139		
08				1098397.849	0578209.532
	S 86°-02'-44" W	266°-02'-44"	00322.111		
09				1098375.635	0577888.188
	N 06°-23'-59" E	006°-23'-59"	08484.074		
10				1106806.841	0578835.854
	N 68°-04'-55" W	291°-55'-05"	05775.919		
11				1108962.888	0573475.450
	N 03°-14'-26" E	003°-14'-26"	00306.519		
12				1109268.916	0573492.757
	N 03°-39'-51" E	003°-39'-51"	00746.907		
13				1110014.296	0573540.492
	N 21°-06'-29" E	021°-06'-29"	00350.360		
14				1110341.148	0573666.666
	S 48°-04'-25" E	131°-55'-35"	02768.647		
15				1108491.202	0575726.546
	N 28°-05'-24" E	028°-05'-24"	00276.144		
16				1108734.818	0575856.571
	N 41°-12'-36" E	041°-12'-56"	01015.073		
17				1109498.392	0576525.397
	N 52°-18'-53" E	052°-18'-53"	00497.776		
18				1109802.695	0576919.327
	N 62°-12'-03" E	062°-12'-03"	01056.133		
19				1110295.249	0577853.369
	N 67°-42'-01" E	067°-42'-01"	00875.334		
20				1110627.395	0578663.459
	N 62°-32'-55" E	062°-32'-55"	00208.725		
21				1110723.634	0578848.652
	N 54°-24'-16" E	054°-24'-16"	02262.408		
22				1112040.487	0580688.323
	N 64°-35'-06" E	064°-35'-06"	00512.316		
23				1112174.525	0580970.414
	N 71°-50'-36" E	071°-50'-36"	00443.125		
24				1112312.610	0581391.475
	N 81°-00'-53" E	081°-00'-53"	00598.801		
25				1112406.131	0581982.928
	S 88°-55'-51" E	091°-04'-09"	02845.214		
26				1112353.041	0584827.646
	S 88°-59'-37" E	091°-00'-23"	02023.722		
27				1112317.496	0586851.056
	S 88°-59'-37" E	091°-00'-23"	02712.485		
28				1112269.854	0589563.125
	S 89°-01'-22" E	090°-58'-38"	02013.602		
29				1112235.511	0591576.451
	N 86°-27'-16" E	086°-27'-16"	00369.128		
30				1112258.339	0591944.853
	N 63°-08'-42" E	063°-08'-42"	00405.738		
31				1112441.626	0592306.833
	N 46°-14'-33" E	046°-14'-33"	01794.438		
32				1113682.670	0593602.911
	N 46°-12'-14" E	046°-12'-14"	02069.318		
33				1115114.836	0595096.556
	N 57°-19'-37" E	057°-19'-57"	00184.735		
34				1115214.549	0595252.069
	N 34°-38'-22" E	054°-38'-22"	00352.580		
35				1115418.594	0595539.608
	N 65°-27'-03" E	065°-27'-05"	00379.918		
36				1115588.405	0595879.464
	N 81°-34'-28" E	081°-34'-28"	00891.951		
37				1115719.095	0596761.769
	S 89°-41'-16" W	269°-41'-16"	04756.316		
38				1115693.284	0592025.322
	N 21°-48'-21" E	021°-48'-21"	19702.614		
39				1133986.150	0599344.070

FIELD



INPUT: Kg A N
E
Kg B N
E
Pt C N
E
Pt D N
E

OUTPUT: Pt O N
E
Distance AO
Distance OB
Distance CO
Distance OD
Angles AOC and B
Angles AOD and B

PROGRAM LENGTH: 5 Track

DATA STORAGE: 1 Track

SUBROUTINES USED:
1. Data
2. Data
3. Squa
4. Arcta
5. Alpha
6. Coord
7. Coord
8. Angl
9. Azim
10. Dista

COMPUTATION TIME: 1½ min

PT1NB - PC2NB

7'005'734830'137'1735862'468'734141'988'1733388'761'735143'078'
287'436'-0000000''

ate = 1735306.904 feet
ate = 734668.978 feet
00234.173 feet
00765.750 feet
01975.863 feet
09925.342 feet
BOD = 029°-36'-17"
BOC = -150°-23'-43"

PT3SB - PC4SB

7'005'734830'137'1735862'468'734141'988'1734610'''-'--'610'454'
68'986'-0000000''

te = 1735635.879 feet
te = 734356.924 feet
00687.607 feet
00312.316 feet
01056.613 feet
09535.239 feet
OD = 029°-36'-17"
OC = -150°-23'-43"

PT1NB - PC2NB

'660'733374'977'1740105'927'733660'792'1733388'761'735143'078'
87'436'-0000000''

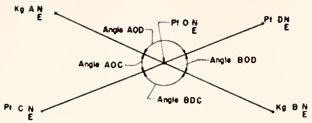
te = 1739779.633 feet
te = 733563.470 feet
00659.483 feet
00340.500 feet
06583.190 feet
05318.015 feet
OD = -030°-29'-28"
OC = 149°-30'-32"

PT3SB - PC4SB

'660'733374'977'1740105'927'733660'792'1734610'132'734610'454'
58'986'-0000000''

te = 1739356.586 feet
te = 733437.291 feet
00218.019 feet
00781.964 feet
04889.286 feet
05702.566 feet
D = -030°-29'-28"
C = 149°-30'-32"

FIELD STAKEOUT NO. 2



INPUT:
Kg A N
E
Kg B N
E
Pt C N
E
Pt D N
E

OUTPUT:
Pt O N
E
Distance AO
Distance OB
Distance CO
Distance OD
Angles AOC and BOD
Angles AOD and BOC

PROGRAM LENGTH: 5 Tracks

DATA STORAGE: 1 Track

SUBROUTINES USED:
1. Data Input
2. Data Output
3. Square Root
4. Arctangent
5. Alphanumeric Output
6. Coordinate Input
7. Coordinate Output
8. Angle Output
9. Azimuth Computation
10. Distance Computation

COMPUTATION TIME: 1½ min. per problem approximately.

```
.0003400

KD8 - KD9 and Sta. 0+00NB - PC1NB

0+213300'1725823'869'733623'049'1726763'586'733281'275'1726395'505'733133'177'
1729315'942'734655'621'-0000000'
0+293363'7'-0000000''

Pt O  N Coordinate          =  1726714.114    feet
      E Coordinate          =   733299.268    feet
Distance AO   =  00947.294  feet
Distance OB   =  00052.645  feet
Distance CO   =  00359.300  feet
Distance OD   =  02934.146  feet
Angles AOC and BOD          =  047°-31'-11"
Angles AOD and BOC          = -132°-28'-49"


KD10 - KD11 and PT1NB - PC2NB

0+213300'1727206'593'733049'303'1727843'206'733820'526'1727386'111'
733265'963'1729283'533'733664'659'-0000000''

Pt O  N Coordinate          =  1727385.297    feet
      E Coordinate          =   733265.791    feet
Distance AO   =  00280.716  feet
Distance OB   =  00719.314  feet
Distance CO   =  00000.834  feet
Distance OD   =  01939.692  feet
Angles AOC and BOD          = -038°-35'-42"
Angles AOD and BOC          =  141°-24'-18"


KD11 - KD12 and Sta. 0+00NB - PC1NB

0+213300'1727843'206'733820'526'1728001'012'734655'803'1726395'505'733133'
177'1729315'942'734655'621'-0000000''

Pt O  N Coordinate          =  1727857.321    feet
      E Coordinate          =   733895.231    feet
Distance AO   =  00076.027  feet
Distance OB   =  00774.026  feet
Distance CO   =  01648.523  feet
Distance OD   =  01644.923  feet
Angles AOC and BOD          = -051°-46'-05"
Angles AOD and BOC          =  128°-13'-35"


KD19 - KD20 and PT1NB - PC2NB

0+213300'1733105'759'734495'899'1734156'648'735027'103'1733388'761'735143'078'
1744942'288'732287'436'-0000000''

Pt O  N Coordinate          =  1734058.568    feet
      E Coordinate          =   734977.525    feet
Distance AO   =  01067.617  feet
Distance OB   =  00109.900  feet
Distance CO   =  00689.962  feet
Distance OD   =  11211.243  feet
Angles AOC and BOD          = -040°-41'-57"
Angles AOD and BOC          =  139°-18'-03"


KD21 - KD22 and PT1NB - PC2NB

0+213300'1735157'005'734830'157'1735862'468'734141'988'1733388'761'735143'078'
1744942'288'732287'436'-0000000''

Pt O  N Coordinate          =  1735306.904    feet
      E Coordinate          =   734668.978    feet
Distance AO   =  00234.173  feet
Distance OB   =  00765.750  feet
Distance CO   =  01975.863  feet
Distance OD   =  09925.542  feet
Angles AOC and BOD          =  029°-36'-17"
Angles AOD and BOC          = -150°-23'-43"


KD21 - KD22 and PT3SB - PC4SB

0+213300'1735157'005'734830'157'1735862'468'734141'988'1734610'''---''610'454'
1744892'537'732068'986'-0000000''

Pt O  N Coordinate          =  1735635.879    feet
      N Coordinate          =   734356.924    feet
Distance AO   =  00687.607  feet
Distance OB   =  00312.316  feet
Distance CO   =  01056.613  feet
Distance OD   =  09535.239  feet
Angles AOC and BOD          =  029°-36'-17"
Angles AOD and BOC          = -150°-23'-43"


KD25 - KD26 and PT1NB - PC2NB

0+213300'1739147'660'733574'977'1740105'927'733660'792'1733388'761'735143'078'
1744942'288'732287'436'-0000000''

Pt O  N Coordinate          =  1739779.633    feet
      N Coordinate          =   733563.470    feet
Distance AO   =  00659.483  feet
Distance OB   =  00340.300  feet
Distance CO   =  06583.190  feet
Distance OD   =  05318.015  feet
Angles AOC and BOD          = -030°-29'-28"
Angles AOD and BOC          =  149°-30'-32"


KD25 - KD26 and PT3SB - PC4SB

0+213300'1739147'660'733574'977'1740105'927'733660'792'1734610'152'734610'454'
1744892'537'732068'986'-0000000''

Pt O  N Coordinate          =  1739356.586    feet
      N Coordinate          =   733457.291    feet
Distance AO   =  00218.019  feet
Distance OB   =  00781.964  feet
Distance CO   =  04889.286  feet
Distance OD   =  05702.566  feet
Angles AOC and BOD          = -030°-29'-28"
Angles AOD and BOC          =  149°-30'-32"
```

Highway Profile NB CONTRACT 7D-2

```
0+172500'36080'38300'42170'44390'46620'
47740'49660'50800'-0000000'
2+102600'20050'19100'15672'19004'19227'
17900'18800'21308'-0000000'
0+172700'600'600'600'600'600'600'600'0'-0000000'
0+172800'37200'44500'50'-0000000''
```

PROFILE

GRADE	STATION	ELEVATION On Grades	On V. Cur.	Correction for V. Cur.	DISTANCE
-0.43 %	37200.000	195.71			
-0.43 %	37250.000	195.49			
-0.43 %	37300.000	195.28			
-0.43 %	37350.000	195.07			
-0.43 %	37400.000	194.85			
-0.43 %	37450.000	194.64			
-0.43 %	37500.000	194.42			
-0.43 %	37550.000	194.21			
-0.43 %	37600.000	194.00			
-0.43 %	37650.000	193.78			
-0.43 %	37700.000	193.57			
-0.43 %	37750.000	193.35			
-0.43 %	37800.000	193.14			
-0.43 %	37850.000	192.93			
-0.43 %	37900.000	192.71			
-0.43 %	37950.000	192.50			
-0.43 %	38000.000	192.28			
-0.43 %	38050.000	192.07	192.06	-000.01	
-0.43 %	38100.000	191.86	191.82	-000.04	
-0.43 %	38150.000	191.64	191.56	-000.09	
-0.43 %	38200.000	191.43	191.28	-000.15	
-0.43 %	38250.000	191.21	190.98	-000.24	
-0.43 %	38300.000	191.00	190.66	-000.34	
-0.89 %	38350.000	190.56	190.32	-000.24	
-0.89 %	38400.000	190.11	189.96	-000.15	
-0.89 %	38450.000	189.67	189.59	-000.09	
-0.89 %	38500.000	189.23	189.19	-000.04	
-0.89 %	38550.000	188.79	188.78	-000.01	
-0.89 %	38600.000	188.34	188.34	000.00	
-0.89 %	38650.000	187.90			
-0.89 %	38700.000	187.46			
-0.89 %	38750.000	187.01			
-0.89 %	38800.000	186.57			
-0.89 %	38850.000	186.13			
-0.89 %	38900.000	185.69			
-0.89 %	38950.000	185.24			
-0.89 %	39000.000	184.80			
-0.89 %	39050.000	184.36			
-0.89 %	39100.000	183.91			
-0.89 %	39150.000	183.47			
-0.89 %	39200.000	183.03			

0+170300'37950'-0000000'2+100301'19250'-0000000'0+290302'6'-0000000'0+100400'76'44'34'25'0'-0000200'-0000000'
1+100500'1934'1936'1934'1934'1939'1941'-0000000''

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
37950.000	cut	m4onl	193.57622	047.80498	n4onl	193.95934	-059.33745		00324.695

0+170300'38000'-0000000'2+100301'19228'-0000000'0+290302'6'-0000000'0+100400'88'44'0'-0000038'-0000110'
-0000200'-0000000'1+100500'1927'1924'1924'1934'1934'1935'-0000000''

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38000.000	cut	m4onl	192.40000	043.98010	n4onl	193.40000	-057.98010		00244.125

0+170300'38050'-0000000'2+100301'19207'-0000000'0+290302'4'-0000000'0+100400'88'44'0'-0000200'-0000000'
1+100500'1918'1921'1924'1934'-00000000''

0+170300'38100'

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38050.000	cut	m4onl	192.10252	043.63019	n4onl	192.67969	-055.93888		00228.894

0+170300'38100'-0000000'2+100301'19186'-0000000'0+290302'4'-0000000'0+100400'44'0'-0000085'
-0000200'-0000000'1+100500'1914'1913'1914'1930'-0000000''

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38100.000	cut	m4onl	191.39463	041.63863	n4onl	191.36059	-051.50246		00145.889

0+170300'38150'-0000000'2+100301'19164'-0000000'0+290302'5'-0000000'0+100400'44'0'-0000066'-0000165'
-0000200'-0000000'1+100500'1907'1908'1914'1914'1912'-0000000''

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38150.000	cut	m4onl	190.70959	039.77848	n4onl	191.27302	-052.03218		00126.834

0+170300'38350'-0000000'2+100301'19032'-0000000'0+290302'5'-0000000'0+100400'44'12'0'-0000085'-0000200'
-0000000'1+100500'1869'1874'1878'1874'1874'-0000000''

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38350.000	fill	m4onl	187.13037	029.25664	n4onl	187.65813	-030.14749	00050.613	

0+170300'38400'-0000000'2+100301'18996'-0000000'0+290302'3'-0000000'0+100400'44'0'-0000200'-0000000'
1+100500'1854'1864'1854'-0000000''

STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38400.000	fill	m4onl	185.63155	033.81191	n4onl	186.22786	-034.48858	00115.228	

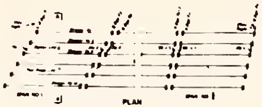
0+170300'38500'-0000000'2+100301'18919'-0000000'0+290302'5'-0000000'0+100400'44'11'0'-0000065'-0000183'
-0000000'1+100500'1831'1834'1839'1854'1854'-0000000''

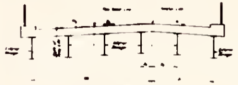
STATION	SECTION		POINT TOWARD MALL			POINT AWAY FROM MALL		FILL AREA	CUT AREA
		SLOPE	ELEVATION	OFFSET	SLOPE	ELEVATION	OFFSET		
38500.000	fill	m4onl	183.12964	040.73954	n4onl	184.75901	-037.82395	00227.082	

DIVISION OF CONSTRUCTION - HIGHWAYS

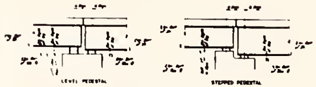
		PROFILE				EXCAVATION		BALANCE	EMBANKMENT	
GRADE	STATION	ELEVATION On Grades	On V. Cur.	Correction for V. Cur.	DISTANCE	AREA	CUBIC FEET	Rock Excav	AREA	CUBIC FEET
-0.43 %	37200.000	195.71			50	0				
							4975			
-0.43 %	37250.000	195.49				199				
							10775			
-0.43 %	37300.000	195.28				232				
							12150			
-0.43 %	37350.000	195.07				254				
							14925			
-0.43 %	37400.000	194.85				343				
							15375			
-0.43 %	37450.000	194.64				272				
							16150			
-0.43 %	37500.000	194.42				374				
							18450			
-0.43 %	37550.000	194.21				364				
							19500			
-0.43 %	37600.000	194.00				416				
							22675			
-0.43 %	37650.000	193.78				491				
							25425			
-0.43 %	37700.000	193.57				526				
							27250			
-0.43 %	37750.000	193.35				564				
							29375			
-0.43 %	37800.000	193.14				611				
							29375			
-0.43 %	37850.000	192.93				564				
							26350			
-0.43 %	37900.000	192.71				490				
							20375			
-0.43 %	37950.000	192.50				325				
							14225			
-0.43 %	38000.000	192.28				244				
							11825			
-0.43 %	38050.000	192.07	192.06	-000.01		229				
							9375			
-0.43 %	38100.000	191.86	191.82	-000.04		146				
							6825			
-0.43 %	38150.000	191.64	191.56	-000.09		127				
							5150			
-0.43 %	38200.000	191.43	191.28	-000.15		79				
							3875			
-0.43 %	38250.000	191.21	190.98	-000.24		76				
							3775			
-0.43 %	38300.000	191.00	190.66	-000.34		75			0	
							2075			1275
-0.89 %	38350.000	190.56	190.32	-000.24		8			51	
							200			4150
-0.89 %	38400.000	190.11	189.96	-000.15		0			115	
										7275
-0.89 %	38450.000	189.67	189.59	-000.09					176	
										10075
-0.89 %	38500.000	189.23	189.19	-000.04					227	
										12100
-0.89 %	38550.000	188.79	188.78	-000.01					257	
										12975
-0.89 %	38600.000	188.34	188.34	000.00					262	
										13425
-0.89 %	38650.000	187.90							275	
										13900
-0.89 %	38700.000	187.46							281	
										14250
-0.89 %	38750.000	187.01							289	
										15125
-0.89 %	38800.000	186.57							316	
										16125
-0.89 %	38850.000	186.13							329	
										16925
-0.89 %	38900.000	185.69							348	
										17575
-0.89 %	38950.000	185.24							355	
										17925
-0.89 %	39000.000	184.80							362	
										18050
-0.89 %	39050.000	184.36							360	
										19325
-0.89 %	39100.000	183.91							413	
										21725
-0.89 %	39150.000	183.47								
						TOTAL	350450		TOTAL	232200

BRIDGE GEOMETRY-COMPUTATION OF BEARING ELEVATIONS AND V C CAMBERS

PROFILE

PLAN



SECTION A-A



CONDITIONS AT PIER PEDESTAL

INPUT

Profile Information
- PVI Sta
- PVI Elev
- Length of V.C.
- G1-Incoming Grade
- G2-Outgoing Grade

Bridge Geometry Information
- Skew Angle θ_1 No of Brg Lines n_1
- Skew Angle θ_2 No of Brg Lines n_2
- (Note $n=n_1+n_2$ Total No of Brg Lines)
- s_1 & s_2-Cross Slopes
- K-Constant Elev Diff between Station Line & Theo Grade Line
- No of Stringers, m
- Stringer Offsets from Station Line
- Stations of ℄ Brgs, Sta 1, Sta 2, Sta 3, ...Sta n

Bridge Structural Information
- Depths of Masonry & Str for
  - Ext Str & Int Str of Span No 1,
  - Ext Str & Int Str of Span No 2,
  - Ext Str & Int Str of Span No
- Min Depths of Brg for
  - ℄ Brgs 1, ℄ Brgs 2 ℄ Brgs n

OUTPUT
- Elev Bott of Mas. Pl. of All Bearings
- Depth of All Bearings
- V C Camber of All Stringers

PROGRAM LENGTH
- 15 Tracks

DATA STORAGE
- 16 Tracks

SUBROUTINES USED
1. Data Input
2. Data Output
3. Sin-cos
4. Alphanumeric Output

COMPUTATION TIME
- Varies according to No of Stringers & No of Brg Lines
- For the bridge shown, with 8 Stringers & 16 Brg Lines,
  - Computing Time 3 min
  - Printing Time 30 min
  - Total Time 33 min approximately

[illegible]

[illegible]	[illegible]

Discussion on

The Use of Electronic Computation in Bridge Design and Bridge Geometrics

<u>Moderator</u>

J. O. Morton--Commissioner, New Hampshire
State Highway Department

Paul Yeager--Washington Department of Highways

C. A. Marmelstein--Georgia State Highway Department

R. E. Shields--California Division of Highways

R. C. Vogt--Vogt, Ivers, Seaman & Associates
Cincinnati, Ohio

Elmer K. Timby--Howard, Needles, Tammen & Bergendoff
New York, New York

L. R. Schureman--U. S. Bureau of Public Roads

Mr. Sheridan: Gentlemen - I now take great pleasure in introducing to you another of the leading highway administrators of the Northeast, Mr. John O. Morton, Commissioner of the New Hampshire State Highway Department, who will chair the panel discussion on "The Use of Electronic Computation in Bridge Design and Bridge Geometrics." This is a very important subject and I am sure that Mr. Morton and his panel will have a very interesting message for you.

J. O. Morton
Commissioner
New Hampshire State Highway Department

Mr. Sheridan, members of the panel, ladies and gentlemen. First of all I would like to compliment the Massachusetts Department of Public Works, the Massachusetts Institute of Technology, the American Association of State Highways, the Association of Highway Officials of the North Atlantic States, and the Bureau of Public Roads for their untiring efforts in preparing this conference and for stimulating such wide spread interest in the program. I feel that the purpose of the conference has been adequately covered at the morning session so I will not devote any remarks to that particular stage. I have learned that at previous conferences that have been held in other parts of the country, it was extremely difficult to schedule adequate time for audience participation. I shall endeavor to keep this program on schedule and I will ask that you note your questions as the formal presentations are made in order that we may have them from the floor during the period for the general discussion.

I suppose it is possible for many of us to look back at the time when a large number of our highways were unpaved. As we have expanded and developed our highway systems, a great change has taken place in the field of construction methods and in the concepts of highway design. Today we have an extensive system of expressways in this country with long tangents, flat curves, slight grades. Often times it is said that the automotive industry has more than kept ahead of the highway engineer and the highway program, and certainly today we have a great mass of vehicles capable of high speeds for long periods of time. Some of these vehicles are known as turnpike cruisers and land cruisers.

However, I feel that, as far as a highway engineer is concerned, he does not need to take a back seat to the automotive engineer, for today the highway engineer is cruising at turnpike speeds in the field of highway design through aerial photography, photogrammetry, new drafting techniques, ability to produce plans, and make computations rapidly. We are far advanced over a few years ago. The application of electronic computers to highway

design is entirely new to us, and I am sure there is much to be gained from our explorations in this new field of endeavor. As these programs are developed and understood and used by engineers, we will be cruising at even higher speeds in the field of highway design.

However, in our large mileage of highways and expressways we still have some sections of our highway system that are difficult to negotiate and require time and patience to travel. Sometimes I wonder if this phase of computer activity might be compared to one of our slow sections of highways. It requires time and patience to negotiate. I am sure that the panel assembled for this session is ably qualified to give us the answer to this question and many others that might be similar to it. The panel truly represents a national cross section of interest in bridge design. We have representatives of the bridge departments from three States, namely California, Georgia and Washington. In addition, we have with us members of two engineering consultant firms, and last but not least a representative of the U. S. Bureau of Public Roads.

Before proceeding with the panel discussion I would like to address just a remark or two to the members of the panel. I can assure you that your papers will be printed in the proceedings of the conference and I do feel sure that if you want to deviate from your prepared statements you may feel free to do so. I would say, however, that it is important that we do adhere to this closely timed schedule.

I have listed three or four questions that are of particular interest to me and I do hope that the members of our panel will cover questions of this nature in their presentations. One that I noted was that I would like to know something about the computer programs that have been developed to date by the various States and consultant firms. Second I would like to know the extent to which these programs have been employed and the degree of success obtained with the programs. I would also like to know something about the type of computer equipment employed and the practicability of small States and consultant firms have this equipment in their own offices. Then I would be particularly interested in obtaining information as to the acceptance of these computer programs by the engineering personnel in State highway departments or in consultant firms. These programs are new to us, and I feel that in many cases in the highway field we are driven so hard to turn out work that we do not have the opportunity of sitting down at conferences like this and finding out just exactly what the acceptance has been. I can assure you that all members of this panel have excellent technical backgrounds and know the field of electronic computations and bridge design to the extent that they really can speak with authority on the subject.

Now to proceed with our panel, I am going to change a little bit the order of the participation by the members of the panel. I understand that it is agreeable that I can do that if I would like to, and first of all I would like to present to you Mr. Paul Yeager, who is the structural engineer for the Washington Department of Highways.

Paul Yeager
Structural Engineer
Washington Department of Highways

THE COMPUTATION OF INFLUENCE LINES FOR CONTINUOUS FRAME BRIDGES

Nearly all of the highway bridges constructed in the State of Washington are of special design. Since we are far from the source of steel and do have an abundance of good concrete aggregate, practically every bridge built, except long spans of requiring a steel truss, is made of reinforced concrete. The most economical type of concrete bridge, to date, is the one designed as a continuous frame. Also our mountainous terrain precludes the use of more or less standard bridges so prevalent in many parts of the country.

With the thought in mind that most designs are special, when we began programing bridge design for the electronic computer to save engineering time, we felt that we had to have a very universal program. This program had to be so general that it would be of help to every designer, no matter how special his problem might be.

One of the tedious and time-consuming steps in the design of continuous frames is the distribution of the moments and the calculation of the influence lines. The Computer Section of the Washington Department of Highways felt that this was one of the structural problems that should be adapted to an electronic computer solution, so, immediately after its organization in October, 1956, work was begun on this program.

We now have a working program which will distribute the moments throughout a fifteen-span continuous frame structure, taking into account the moments in columns which may be constructed integrally with the girders. Thus we can handle nearly any type of bridge structure including long bridges with intermediate hinges.

Perhaps it should be mentioned at this point that there are at least two recognized basic methods for designing continuous structures. These are by slope-deflections and by moment distribution. It is entirely possible that the former method would lend itself more readily to machine methods of computation, but there are two good reasons why moment distribution was chosen. In the first place, one program can be set up to solve any number of spans, either with or without integral columns. Secondly, there are many tables and charts available for use with moment distribution, and almost all engineers are familiar with its use. For selling a program after it is written, the importance of this last point should not be overlooked.

To make use of the electronic computer program as a help in his work, the designer is supplied with a very simple form to be filled out and sent to the Computer Section. He calculates the distribution coefficients at each joint and the carryover factors in each span. He also determines the fixed-end moments at the ends of any members he has loaded. These fixed-end moments can be due to any type of loading, dead load, live loads, unit loads moving across the bridge or merely unit fixed-end moments. Each set of fixed-end moments is distributed by the electronic computer along the entire bridge. The designer receives back a listing of the original input and the distributed moments. Machine time is very short and good service can be given by the Computer Section.

By distributing moments for him it was thought that the engineer would be relieved from considerable tedious work and this is still felt to be true in the cases of long complex structures of varying span and column lengths. However, the Bridge Division felt that the program was not complete enough. Therefore we set out to expand it.

The first thought was to have the electronic computer furnish the distribution and carryover factors. We found that the State of Nebraska had a very excellent program for doing this and we obtained it from them. We now offer our Bridge Division this service. This program is particularly useful in cases where the girders, columns or piers are of unusual shape, not readily found in tables.

Another tedious problem confronts the bridge designer. This is the placement of the live loads to produce maximum stresses in each member. There are two ordinary methods of attacking this problem. One may be called the method of trial and error. This, to be successful, requires a great deal of experience to be able to place loads in just the right place to produce maximum stresses. The other method is by the use of influence lines.

Since the electronic computer has not been able to acquire experience, the calculating of influence lines was obviously the next step to be combined with the moment distribution program. Briefly, influence lines are lines showing the moment at a particular point in a bridge structure due to a load moving across the structure. By using these lines the designer can quickly find the maximum moment in a span or can obtain complete moment curves for the bridge due to varying conditions of loading.

The program as now written has two different types of output. The first is for rough approximations and for designers who are very familiar with the construction of moment curves. This type applies the load only at the three-, five-, and seven-tenths points in each span and gives an influence line only at these points. The advantage of this type is that

the program runs faster and the quantity of data produced is less. The second type applies loads at every tenth-point across the structure and gives an influence line for each tenth-point also. This is used where a complete design is needed, as for bar cut-offs or cover plates.

As can be seen, a considerable mass of information is produced by this program. However, this can be tabulated into a very convenient form and it is hoped that the designer can pick his moments directly from the table and not have to plot the actual influence lines. (This plotting of the many influence lines is the principal drawback to this method of bridge design.) If, for live loading, the designer uses his wheel-load as the input, he need add together two or, at the most, three numbers to get the moment at any point. Any interpolation necessary would be simple. An actual byproduct of the electronic computation, but a useful one, is the shear at each end of the span. This is also tabulated. Although the moment distribution portion of the program has been retained and can still handle fifteen spans, the influence line portion has been limited to five spans because of the large volume of output.

This program is now complete and ready to be offered to the Bridge Division as another service to save them engineering time. Our next planned addition to this program will be the correction for sidesway.

This brings up another point which might be well to discuss here. Much has been said about writing electronic programs to increase engineering productivity, but it appears that there are two other problems as large, or possibly larger, than the actual writing of the program. One is to determine what programs to write. In the field of structural engineering, particularly in bridge design, there are two approaches to this. One is to have in the actual design office men who are familiar with computer applications and who can write programs. This is unsatisfactory because the press of design work never allows them time to study and work out computer programs. The second arrangement is to have a structural engineer in the computer section. This is probably a better set-up, but here the engineer soon gets out of touch with the bridge design section's needs and is at a loss to know what is needed. Then, too, he is apt to have his own "pet" programs and will write them, whether needed or not. Probably the best solutions are the conferences like this one where we can see what programs others have written and how successful they are. In the northwest, we have organized a small group governmental users of electronic computers, with meetings about every two months. We have found these conferences to be very useful in determining what programs should be written and whether or not the ones we are working on are worthwhile.

The other problem confronting an engineering data processing unit is the selling of the program after it is written. Experience has shown this to be a difficult problem. Engineers, being very methodical persons, do not take well to a new routine. Even when they have been clearly shown

that you can save them time, effort and worry, they are still reluctant to send you work. We have tried several things to overcome this reluctance, with varying degrees of success. We have tried selling campaigns. Where allowed, we have conducted classes and lectures and where this has not been permitted we have tried to sell the men individually. We feel that one of our more successful approaches has been by having "conducted tours" where the men, from the stake-artist up, see the complete operation from key-punching through the electronic calculator to the final listing. Men who are familiar with our processing methods are more apt to trust and use our services. Next are the simplified forms mentioned earlier. An engineer will shy away from a complicated form. Finally, we try to remember that speed and accuracy are our most important duty.

In closing I would like to just mention some of the other structural engineering problems we have adapted to the electronic computer. These are:

1. I-beam section properties in which the output is a table of areas, moments of inertia, locations of neutral axis and section moduli.

2. T-beam analysis, the output of which is a table of moment of resistance, area of steel, jd and kd.

3. Beam camber computation, developed by Nebraska.

Another application, not strictly in the structural field but which will be very useful, is the determination of the stability of embankments by the Swedish method.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

C. A. Marmelstein, Bridge Engineer
Georgia State Highway Department

PROGRESS REPORT NUMBER TWO ON THE USE OF THE MAGNETIC DRUM DATA-PROCESSING MACHINE IN BRIDGE WORK IN GEORGIA

Our first progress report was made before the Western Conference on Increasing Highway Engineering Productivity in Los Angeles last March. The period covered by that report started August 1, 1956.

It was on that date that the Georgia State Highway Department entered into an agreement with Rich Electronic Computer Center of Georgia Institute of Technology. The agreement provided for programing of problems for the Bridge Division and set up basis for payment for personnel charges, machine time and supplies. The Computer Center has no structural engineers but their personnel include highly trained programers together with several men who have degrees of Doctor of Philisophy in mathematics. The structural engineer of the team was selected from our own organization. He is a man with a Master Degree in Civil Engineering, he has taught Civil Engineering for several years and he has a profound understanding of classical methods of structural analysis. His only preparation for the assignment was a one-week course at I.B.M. However, the year he has spent in close consultation with the programers of the Computer Center has, in my opinion, qualified him to program bridge problems for the I.B.M. 650.

We are well pleased with the progress of the group, our representative and the personnel of Rich Computer Center. The practical effect of our agreement is the placing on our payroll trained programers and mathematicians for the period they are needed and only when they are needed.

The first problem we selected for solution by the magnetic drum data-processing machine was the geometrics of bridges on horizontal curves with substructure not on radial lines. We are encountering more bridges of this type in the higher type geometric design now being employed on our highways. As an illustration, I recently "called the roll" in our drafting room and found that, of 170 bridges on the boards or in backlog, only 38 were on tangent and had normal substructure. The remaining 132 varied from bridges on tangent with skewed substructure to the wierdest kind of geometry.

This problem of skewed bridges on curved alignment is solved by the application of trigonometry and analytic geometry. Depending on the number of spans in the structure and the number of beams per span, using a desk automatic square root electric calculator, the solution requires from about one week to as much as three weeks' time. In general, the information needed is that necessary to detail beams, to determine their lengths; the information necessary to detail anchor bolt spacing based on beam spacing along caps; and grade information to permit determination of bridge seat elevations. Other information helpful in

detailing such a structure are middle ordinates to concentric circles to chords on which beams are set, angles between chords and bents, and slopes of beams.

We completed the program and have been employing it about nine months. As yet we have encountered no failure of the program in producing accurate results.

The program is based upon simple horizontal curves using arc definition, with beams placed on chords to concentric circles. There are three cases. Case 1 covers bridges whose bents are not parallel to one another. Cases 2 and 3 cover bridges whose bents are parallel to one another as in the case of grade separation structures where the bents are parallel to the highway being overpassed. Cases 2 and 3 differ in that one covers the case where bents are parallel to the X axis of the geometric layout and the other where bents are parallel to the Y axis.

The program is limited to 17 concentric circles; that is center line curve with a maximum of 8 concentric circles each side. It is limited to five grade changes within the bridge; that is not more than six PVC and PVT points. There is no limit to the number of spans.

Three hundred eighteen cards make up the program deck. These are loaded in less than two minutes.

Input data are divided into two groups which we have chosen to call "Constant Data" and "Per Bent Data". The Constant Data is the same for all cases and consists of radii of all concentric circles for which solution is desired, together with grade data. Per Bent Data differs with the case. For Case 1 it consists of station number of each bent and its skew angle. For Cases 2 and 3 it consists merely of horizontal perpendicular distances from a base line, such as center line of highway being overpassed, to control line of each bent.

Time required to calculate is less than 4 seconds per bent per radius. In other words, if the problem involved eleven concentric circles, calculating time would be about 40 seconds per bent.

Output consists of the following:

1. Station number of each bent.
2. Elevations at points of intersection of the radial line through each beam-bent intersection and the center line of roadway.
3. The distances between concentric circles measured along the bents.
4. Lengths of all chords to concentric circles between bent control lines.
5. Middle ordinate of each chord.
6. Angles between all chords and bents.
7. The slope of each chord.

As the problem is coded 1976 of the 2000 drum locations provided by the I.B.M. 650 are utilized. Only 24 remain unused. We feel we have obtained the maximum amount and types of output possible within the limits we have established. Of course there are manual calculations required such as corrections for superelevation. By modification our program could include these calculations, but the modification would sacrifice other output data.

Our designers have received other benefits from the program. They have used it to furnish information helpful in detailing wings of abutments of curved skewed bridges. The program is also used in obtaining data helpful in calculating bridge seat elevations for skewed bridges on tangent. This is accomplished by assuming the bridge is on a very long radius, such as 90,000 feet. In the cases we have checked we found the results correct to the fourth decimal of a foot. While it required about four months to complete the program and put it to use, an additional five months were required to complete the write-up.

The Rich Electronic Computer Center has on file many programs which they claim are useless because of the inadequacy of the write-ups. So we decided our write-up would be as complete and as understandable as we were able to make it. It was our desire that anyone who receives the program be able to put it to use with a minimum of effort and in the shortest time possible. We attempted to eliminate all errors by careful checking and rechecking. We determined to do the best possible within our capabilities.

The program write-up includes statement of the problem with necessary drawings; required input information; output quantities; accuracy and restrictions; volume and time data; glossary of terms and symbols; list of formulae in logical order; requirements and restrictions; sample data sheets and instructions for filling in data; instructions for punching input data cards; machine operating instructions; and sample of printed out-put. In the appendix are the program listing, flow diagram, drum storage layout and wiring diagram. In our opinion all this information is necessary for a complete write-up. Our write-up is in loose-leaf binding to facilitate insertion of addenda and substitution of corrected pages should errors be detected.

We have been furnishing to State highway departments on request what we have termed a "program package". The package consists of:

1. Two copies (one for the Bridge Department and the other for the Computer Section) of the complete write-up.
2. Two copies of a sample problem for each of the three cases solved, each consisting of:
    a. Diagram describing layout of bents.
    b. Constant data sheets from which constant data cards are punched.
    c. Per bent data sheets from which per bent data cards are punched.

3. One deck of punched cards containing:
   a. Program deck as described in the write-up
   b. One test deck for each of the sample problems given each consisting of:
      (1) Constant Data Cards (Green)
      (2) Per bent Data Cards (Yellow)
      (3) Output Cards (Salmon)

Any State highway department that would care to have this "program package" will receive it upon a request written to me, care State Highway Department of Georgia, 271 Capitol Avenue, S. W., Atlanta 3, Georgia.

Our current work consists of programing solution of continuous bridges. The program will be comprehensive. Nine months of effort have gone into this work. The programer experienced many periods of discouragement. However, invariably after consultation with the structural engineer the difficulty was removed. The work is now "over the hill" and only a few months are necessary for completing the program and commencing the write-up.

At the time this paper was written, the first two stages of the problem, namely the computation of the elastic properties of the beam and the determination of maximum moments from all types of loading, have been coded completely in symbolic form, and at present the actual drum locations are being assigned so that this stage can be loaded and tested on the 650.

Since it is not ready for distribution I shall deal with this program briefly. It will solve from two-span to five-span continuous structures with constant or variable moments of inertia. Span lengths need bear no relation to one another. The types of structures covered are: rolled beams, rolled beams with cover plates, plate girders, composite concrete and steel beams built with any type of the steel beams just mentioned, concrete slabs, and concrete T-beams or box girders.

Input data will be of such a nature as to require a minimum amount of computation by the designer. It will consist of the number of spans making the continuous beam, the geometric shape and dimensions of each member, the dead load constants, and the live load classification. A single code number will define the type of beam to be solved, and all the designer has to give is the size or physical properties of the beam. For example, if a beam consists of a rolled section with top and bottom cover plates, the input information will consist of the code number for this type of beam, the depth, area, and moment of inertia of the rolled section (as taken from the steel handbook), and the size and location of the cover plates. If instead, the beam is a plate girder of variable depth of web, and variable size of flange plates, besides the corresponding code number for this beam, the input will consist of the web thickness, the constants that define the depth of the beam at any point (not the depth at every point), and the size and location of the flange plates.

With this information as input, the program will enable the machine to compute the properties of the built up section (depth, area, moment of inertia, etc.) at 40 points along the span, and from these properties, compute the elastic properties of the span (fixed end moments, stiffness factors, carry over factors, etc.). After computing the individual properties of each span, the constants that define the continuity of the beam will be computed, and ordinates of the influence line will be developed for the points where stresses are desired. It may be mentioned here that the only ordinates developed are those required to enable the live loads to be computed, and no ordinates are computed outside the range where maximum stresses are possible, thus considerably reducing the time and storage requirements. Positive and negative areas of influence lines in each span are computed to simplify the computation of stresses due to uniform dead load and live loads.

A code number in the input will define the standard live load to be considered (H-15, H20-S16, etc.). The problem is capable of placing the wheel loads of the truck where required to produce maximum stress, and where the position of the truck cannot be predetermined, it will move the truck along the limits required to insure obtaining the maximum stress. Provisions are contained in the program to consider, when required, the variable spacing of the rear axles of standard H-S loading, as well as the consideration of military loads in the computation of maximum positive live load moments. The stresses produced by the corresponding lane loads are computed, compared to the stresses from the wheel loads and the maximum of the two stresses selected.

The output of the continuous beam problem, when completed, will include the following information:

A. Ordinates to moment curve at each tenth point of each span as follows:

1. Dead load moment due to weight of beam.
2. Dead load moment due to concentrated loads on bridge.
3. Dead load moments due to superimposed uniform dead load.
4. Total dead load moment.
5. Maximum positive moment due to sidewalk live loads.
6. Maximum negative moment due to sidewalk live loads.
7. Maximum positive moment due to standard wheel or lane loading.
8. Maximum negative moment due to standard wheel or lane loading.
9. Total maximum positive moment.
10. Total maximum negative moment.

B. Same as above for shear.

C. Reactions at each support from the various loads.

D. Dead load deflection at each tenth point of each span.

E. Maximum live load deflection in each span.

In addition to maximum stresses the output will also give for 20 points along the beam, moments of inertia, section modulii, depth, and other information that can be of aid to the engineer in designing and detailing the structural member. At present we will only compute the stresses on a given beam, and the designer will have to proportion the member and make adjustments where necessary. Should considerable changes be required in the size of the member, the new beam shape can be fed back to the machine and a new set of stresses obtained. Our programer estimates that the way the program looks now, moments may be computed at a rate of 2 to 4 minutes per Span, so that running through a new computation will take little time in addition to the punching of the few data cards that need be changed. This small amount of time required for machine solution should encourage a more critical attitude toward results. If results are not entirely satisfactory it will be very easy to adjust the section and rerun the problem. It should eliminate what we in Georgia call "fudging".

We must make clear our solution will not be exact. In loading the influence lines we are dealing with a series of ordinates and not curves. In placing loads, one axle is always placed at an ordinate and the effect of the other axles is assumed to have the value determined by straight line interpolation between adjacent ordinates. The movement of the vehicle proceeds until one of the three axles reaches an ordinate. Moments are computed and movement again proceeds until an axle, whichever it might be, reaches an ordinate to the influence line, and moments are again computed.

Influence lines are developed for each tenth point of each span, but each influence line consists of twenty ordinates, which in turn are computed from the properties of the cross section at 40 points equally spaced along each span. The speed and accuracy of computations of the computer makes possible this precision, which otherwise would be prohibitive (time wise) when solving the problem on the desk calculator. The program should provide a solution more accurate than presently achieved by manual methods involving plotting influence lines and moving loads across them. We believe the inaccuracies that may result from the solution will be less than the inherent errors resulting from the normal assumptions made in the present theories of stress analysis and design. In using straight line interpolation for loads falling between ordinates of the influence line, slightly smaller values will be obtained for negative moments, and slightly higher values will be obtained for positive moments, when compared to the values obtained if the ordinate under the load was computed from a smooth curve.

When time permits, features can be added to the program to make it self re-entrant after making the proper adjustments internally. We will then have a complete design program, where the final output will be a member optimously proportioned in size and shape.

We have in mind many more bridge problems which we intend adapting to solution by the magnetic drum data-processing machine. At the start we have attempted to provide solutions for the most time consuming problems.

Programing itself is a very time consuming operation. We can see years of work ahead. The I.B.M. "HEEP" program is very helpful, but the greatest need in this field is a nationwide organization of personnel engaged in programing bridge problems. Such an organization should be formed and it should meet to assign definite problems to each member, and to prevent duplication of efforts. Before work starts the organization should agree on the scope and limits of the problem, the accuracy desired, the output data desired, etc. At Los Angeles program libraries were discussed and will no doubt be discussed at this meeting. The development of programs for such a library is proceeding at snail's pace. At the present time the work appears bogged down. The programs are needed today, not some years in the future. Notable progress will not be achieved unless an organization as described above is activated and is functioning.

J. J. Kozak, Bridge Engineer
R. E. Shields, Associate Bridge Engineer
California Division of Highways

COMPUTER APPLICATIONS IN THE CALIFORNIA BRIDGE DEPARTMENT

Presented by R. E. Shields

The computer has become an indispensable tool in the Bridge Department operations. A number of our engineers now rely entirely upon the machines for their layout and quantity calculations and make full use of the structural program wherever applicable. The rest are in various stages of trying the services for themselves. This situation occurs due to our philosophy of allowing each engineer to decide for himself whether to use the machine service. While this may seem to be somewhat inefficient in this transition stage, we feel that there is great benefit to be derived because as the engineer is free to accept or reject the services of the computer at will, the amount of use depends entirely upon the degree to which the computer is useful and is made to fit the needs of the engineer. In other words, programs which require the engineer to limit his layout or design to fit the machine, to completely change his approach to a problem, or to fill out a form which requires as much time as doing the problem by the hand method, die on the vine in our department. This, we feel is good. After all, none of the machines that we use in this work have the power to make decisions based on four years of college and several years of experience. Therefore, the programs which attempt to force the engineer down to the level of the "Rapid Idiot" should not be forced upon the engineer. Let our services compete freely with the hand method and only when the last sceptic is convinced should we assume that we have completed our programs.

If the engineer is not using the available service to the utmost, there could be several reasons for it.

(1) The need was never important.

(2) The service is not attractive. There are too many fussy preliminary details, preliminary computations or filling out complicated forms.

(3) The service is not flexible enough. The engineer may realize that the problem demands other considerations than were built into the services. He therefore elects to do it by hand and do a proper job.

(4) Perhaps the service is not complete enough. Maybe we are only doing the small job and requiring so much work of the engineer that his natural momentum carries him right through the machine application or,

(5) A successful selling job has not been done. Of course, as with anything new, there is bound to be inertia and some prejudice. This can only be overcome by listening to the complaints, attempting to fix all legitimate complaints and doing everything possible to distribute information about any new techniques involved in using the services.

We classify our services in three groups: layout, structural and quantity, and attempt to carry forward at least one new service in each of these classifications at all times. We further separate our service development into three classifications: programing, checking and modifications.

In the layout classification, we are working at the present time on two projects. We have completed the first phase of our vertical alignment program and have it in operation. Modification of this phase is being held up pending completion of phase 2. In the present phase, we are able to produce a line of grades, a grid of grades at any interval, or compute any specific points on a roadway. This service has definite limitations which will be solved in phases 2 and 3.

The second phase will allow us to continue this grid through superelevation transition portions of the alignment. This program will give a grid of grade and also the grade of all important points on the roadway. This phase will also allow the handling of variable width roadways and equations in the line.

Also in the layout classification, we have been developing what we call our bridge layout system. This system is made up of three existing programs which, when used as tools by the engineer, allow a completely flexible layout of any structure. No limiting conditions are imposed as to framing or physical layout.

This system is an outgrowth of our attempts to write a program to lay out skewed bridges. We found that unless the detail of the input is made so complete as to make it unworkable, any program we studied imposed such severe restrictions upon the engineer that his education, experience, and intelligence are completely wasted. In one case, only one bridge in 214 would serve as an example for testing a completed layout program. We feel that 213 engineers had, for the most part, good reasons for their layout in framing systems which should override any decisions made by the "Rapid Idiot" and therefore that it is very unrealistic to attempt to allow the machine to override the decisions of the engineer.

We therefore supply three tools: two for horizontal alignment, the point on curve and central angle computation service and the traverse computation service, and one for vertical alignment described above. This tool takes the routine, high school arithmetic out of the hand of the engineer, but leaves to him all major decisions as to layout and framing systems for his bridge. There, of course, are no exceptions or no special ground rules for laying out any structure with this system. As to time savings with this system, quite complicated structures have been layed out in four engineer man-hours. The key to this system, we feel, is the newly developed modification to the California traverse program which allows interdependency between separate traverse solutions.

At the present time, further modifications of this system are going on which will combine the two horizontal alignment programs into one program with interdependency.

In the structural field, we have three existing services at this time. They are, first, the design of a welded steel-concrete composite girder; two, the analysis of rectangular columns under bi-axial bending and axial load; and three, the library routine solution of simultaneous equation by matrix inversion.

At the present time we are designing about 200 composite girders per month at about 39 cents per design. This program takes, as the minimum information, the span, spacing, allowable steel stress and structure depth of a girder; and reports, as an answer, all factors for the complete design of the girder including deflections, shear connector data, reactions and flange reduction points. The work done in this design replaces approximately four to six engineer man-hours of computation.

The analysis of rectangular concrete columns is accomplished by the equation given in AASHO design specifications. The input is either the description of the column, including steel placement, or a standard column number. The output is the maximum concrete and steel stress. This program is also designed to allow for the analysis of spread or pile footings under the same loading conditions.

The library routine for matrix inversion has been used for analysis work involving simultaneous equations. For instance, at the present time multi-storied or multi-spanned frames can be analyzed by slope deflection equations, using this program. Work will be started this month on programs which will put data as submitted by the engineer into the form of input cards to the matrix inversion program and to take output cards from the matrix inversion plan and convert them into answers desired by the engineer. This routine has also been used for analysis of arches and of shearing stresses in suspension bridge towers. This seems to be quite a fertile field for possible system types of services.

We are at present programing the prestressed concrete problem. This will be in several phases, the first of which is the composite prestressed girder; that is, the precast girder with cast-in-place slab.

The third classification, quantity calculations, we feel, is one of the most fertile fields for computer applications. There are involved so many repetitious calculations, of a very elementary nature that, except for the take-off from the plans, almost the complete operation can be mechanized. These applications may seem elementary and possibly unimportant when compared with an analysis of long span bridges. However, in time and money saved, we feel that these applications may, in the long run, become the bread and butter of a structural computer installation. We are, at present, offering three services in the quantity calculation classification. The first developed was the extension and summation of concrete reinforcing bar quantities. The input form used is the same as the hand form used prior to the machine application, with the exception of key punch instruction and tick mark to indicate positioning of letters and numbers on the form. A complete description of each bar is possible by an item column which is printed on the output as well as the input. The bars are described as to size by the number system, number of bars and length of bars. The output form lists the bars according to bar size and gives the total length of each bar, the total weight of each bar item and the total of each bar size. They are further broken down into substructure and superstructure items and totals of each are given as well as a total for the whole bridge. This method of tabulation has been found to accelerate checking between two independent quantity calculations as run by our department. The second quantity calculation system to be developed is a standard computation sheet which operates on four numerical factors in four different manners. All four factors can be multiplied together, two of the factors can be summed and the other two summed and the sums multiplied, $(a + b)\ (c + d)$ three of the factors can be summed and multiplied by the fourth, $(a + b + c)d$ or two of the factors can be summed and the sum multiplied by the third and fourth $(a + b)\ (c)\ (d)$. The use of this form requires some ingenuity on the part of calculators and engineers. However, in addition to regular quantity calculations, structure excavation, backfill, concrete quantities, pile quantities, etc., there are also applications in traffic study quantities, arch thrust summation, vertical curve computations and other applications.

The output of the four-factor computation consists of the alphabetic designation or identification, the extension of all quantities and the summation of each line in order by their item number.

The third of our quantity calculation systems is based on the preceding one, the four-factor computation. This service is for the extension and summation of structural steel quantities. The output of this program, of course, is identical with the output of the four-factor computation. The totals given are pounds of structural steel.

The future of our quantity calculations include a program now being done to analyze bid prices and to prepare factors for pricing future jobs. This program will replace the work of about three full time engineers doing work not of an engineering nature. We are studying the Bid Tabulation program of Texas and hope to adopt some of it to our operation. We have under consideration a program for the direct solution of structure excavation and backfill by a system of triangular designation. This program was requested by our field forces.

We feel fairly certain that by this time all of us here know pretty well what a computer does and at what speed, so we feel that perhaps we should spend all of our time attempting to exchange information about our successes and our failures in all phases of this problem of adapting these computers to civil engineering operations. In evaluating a computer program, we offer this test. How often does the engineer use this voluntarily? How much time is saved? Does it have any additional benefits not easily evaluated, such as accomplishing closer design or allowing the engineer to get valuable experience faster?

In closing, we would like to reiterate that these machines cannot, at the present time, match the engineer in experience, intelligence, or feeling for problem. Therefore, any programs which limit or restrict the engineer from doing layout or designs as he used to do them, we do not feel offer the proper service nor do they fulfill the real purposes of the computer installation which is to turn out economical structures as rapidly and with as little work as possible.

R. C. Vogt
Vogt, Ivers, Seaman and Associates

THE USE OF ELECTRONIC COMPUTATION IN BRIDGE PIER DESIGN

At the Western Regional Conference on Increasing Highway Engineering Productivity which was held in Los Angeles in March, we presented a paper describing the analysis of a rigid-frame pier bent for moments due to concentrated vertical loads. The moment distribution method was used in this program. At that time, the program included only the operation of moment-distribution and the next step was to have been the standard correction for sidesway.

However, while studying the original program with the intention of improving and adding to it, the entire pier design problem was closely re-examined and methods were evaluated considering solution by the computer. It became our opinion that, in general, programs which involve simultaneous equations are likely to be more satisfactory than those which involve successive corrections.

Accordingly, Robert McFarlin, one of our structural engineers, working in conjunction with Andrew Barkocy, who is in charge of our Computer Division, undertook the solution of the problem by the use of the equations of slope deflection in a new and separate program. It is largely through their efforts that this advanced program has been developed.

Therefore, the planned additions to the original program have not been made; however, that program has been placed in our program library and is now available. It is quite useful in its limited field of problems which involved symmetrical vertical loads on symmetrical frames.

This paper deals with the new program which, as stated, uses the slope-deflection equations and which has also been very much increased in its scope over our original program. No portion of this new program is complete and available as yet, but it will be made available in sections as each section is completed. The first three steps are presently being coded and we anticipate completion of these parts within a few months. Results of this program will, in general, be in the form of true moments at each end of each member of the frame due to any of the various types of loading which may occur. Planned future steps, and some problems involved in them, will be discussed later in this paper.

At this time, a description will be presented of the scope and usefulness of the program, in the form in which it will first be made available.

A frame one tier in height, with from one to five bays, may be analyzed. There may be as many as three concentrated beam reactions in each bay, and, in addition, the pier cap may be cantilevered on each end, with an additional beam on each cantilever; thus, provision is made for a maximum of seventeen beams or girders which can have their reactions on the frame.

The columns may be circular or rectangular, but must be prismatic. Their heights may vary. The spans of the five bays may also vary. The pier cap must be rectangular, but its depth may vary. A very important feature of the program is that it can be used with the many haunched pier caps of various forms which are used by some designers.

There are, of course, two slope-deflection equations for each member, one equation for the summation of moments around each of the six joints where a column meets the pier cap, and one equation for the summation of horizontal forces; a total of 29 general equations which can be used to solve for the twenty-two moments, one at each end of each member, which are required. These equations involve stiffness of members, three constants per member, fixed-end moments, deflections of members, and joint rotations. It should be noted that the general equations will determine any moments which can be desired from whatever cause, be it a load, temperature change, settlement of support, or whatever other condition may arise. All that is required is to substitute the proper fixed-end moments, deflections, or rotations into the equations and substitute zeros for everything else, and solve.

In Step 1, the program determines the relative stiffness, constants and fixed-end moments (for each unit load) of each member. We call this step, "Solution for Pier Properties."

It is assumed that the locations of all beam reactions are known; also, that all pier dimensions are known. This is not unreasonable, since cap widths are often determined by the size of bearings and amount of skew; and the other features are usually governed by standards or related to the cap width, or both.

The program will first examine the data to see if there are any haunched members. If not, the calculation of relative stiffness, constants and fixed-end moments is very routine, the first being the familiar I/L; the second being known and identical for any prismatic member and related to the familiar carry-over factor of 1/2 as used in moment distribution; and the third being of the form $\frac{ab^2}{L^2}$ as in any structural handbook.

If there are haunched members, the column-analogy is used for their properties, with a finite summation of the segments in the member. This was a very interesting sub-problem, in which we were able to relate the column-analogy to slope-deflection.

The relative stiffness and constants for all members, along with a group of fixed-end moments, are calculated in the computer and punched on a tape ready to be placed again into the computer as data for Step 2.

In Step 2, "Solution of the Equations," the equations are solved in turn for each unit load, or unit deformation which is a part of the net loading of the pier. There are twenty-six such units, each of which requires a solution for the twenty-two moments which it causes in the frame. This large influence table, with twenty-six columns and twenty-two rows, is the result of Step 2. These influence moments are also punched on tape to be used as input data for Step 3.

The twenty-six different causes of moment are as follows:

1. The weight of the pier cap. True moments are obtained directly in this case if the pier cap does not cantilever over the end columns of the bent. Step 1 of the program includes the calculation of pier cap weight and fixed-end moments from the given dimensions.

2. thru 16. The beam reactions. A unit load is placed at each beam location and the influence moments throughout the frame are calculated.

17. A horizontal unit load applied along the axis of the pier cap. These results are used to determine the primary effects of transverse wind and centrifugal force.

18. A 100° rise in temperature. Here the "unit" is 100°, because 1° may yield results in only one or two significant figures. This is the only solution requiring a sidesway correction which is included automatically in the program and the machine uses its own results from solution 17 to make this correction. This solution includes temperature change elongation in the columns, as well as the pier cap, the former being of significance when the columns are not of equal height. Shrinkage stresses are found from this solution in the same manner as stresses caused by temperature drop, that is by calculating the shrinkage as an equivalent temperature drop.

19. and 20. The cantilever ends of the pier cap including beam loads on these ends. Here the unit is a unit moment.

21 thru 26. Settlement of a footing. Here the unit is 0.1 foot, because one-foot is not a realistic settlement.

We have, at present, another program which will determine the pressure at any desired depth due to a given size of footing. We intend to extend this program to determine the amount of settlement of a footing.

In Step 3, "Solution for True Moments," the influence moments obtained from Step 2 are multiplied by the actual loads and the products are added to obtain a true moment. By using a separate program to determine true moments from influence moments, any number of loading conditions can be imposed on the structure to determine which combination of loads will produce the maximum moment. Live load, in particular, which varies with the code being used, can be handled conveniently for all possible load positions.

In this third step, true moments can be obtained for any one particular load or for any combination of loads. For example, to determine true moments due to dead load of a pier cap which cantilevers out beyond the end columns, the program will determine the true moments due to the cantilever ends of the pier cap (solutions 19 and 20) and add these moments to the moments as determined from solution 1, for the portion of the pier cap which does not cantilever.

In a similar manner true moments due to wind load can be determined. The effect on the bent of the wind either on live load or on the superstructure can be handled by a horizontal load along the axis of the pier cap (solution 17) and vertical loads at the proper beam locations.

We have presently arranged the program so that it completely solves each pier twice; once for fixed column bases, and once for hinged bases. In any given pier the truth must lie in the range between these two extremes. We are considering methods of narrowing this range to approach one set of true values.

Summarizing the loading cases capable of solution by this pier program we have the following:

Dead load of pier
Dead load of superstructure
Live load
Impact

Centrifugal force
Transverse wind on superstructure
Transverse wind on live load
Temperature rise
Temperature drop
Shrinkage
Differential settlement of footings

A few items which were not included, and for which we have no present plans, are:

1. The effects of horizontal loads on the columns

2. Frames with non-prismatic columns

3. Pier caps tapered in plan

These are considered to be of only slight practical value.

In the future we expect to incorporate the following:

1. The positive moments near the center of each pier cap member. We anticipate an influence-table approach to this.

2. Shears. This might be an influence-table, also.

3. The moments due to longitudinal forces.

4. Reinforcing steel areas and fiber stresses to correspond with the above design moments. We have a portion of this step already available in other completed programs which analyze reinforced concrete columns.

5. The effect of a continuous footing, especially the distribution of pressure to the soil.

Elmer K. Timby and E. M. Chafets
Howard, Needles, Tammen & Bergendoff

ADAPTATION OF ELECTRONIC COMPUTATION METHODS TO HIGHWAY BRIDGE AND INTERCHANGE DESIGN

Presented By Elmer K. Timby

The work of our firm is in the field of highways and bridges. Approximately two years ago we started our program in electronic computation methods. The design problems which we are now solving with the help of electronic computation programs developed by us fall into four general classes:

Horizontal alinement of roadway and bridge centerlines, including transitions;
Vertical alinement of roadway and bridge profiles, including transitions;
Structural geometry or framing dimensions; and
Design of framed bent piers.

In addition, we have been using an available program for calculating quantities of excavation and fill and are extending our structural geometry and our bent design categories. These additional cases are in process of coding and will be in use within the next several weeks. It is believed that a more descriptive discussion of these four general categories of design problems will be of interest. Our coded programs are handling approximately 90 percent of the related problems in highway and bridge design, including the complex arrangements found in complicated urban interchanges of three level construction.

HORIZONTAL ALINEMENT

Forty different types of input forms are used. Each input form represents an individual type of geometric problem. These individual geometric problems can be grouped under the following general headings:

(a) The balancing of field surveys according to transit rule. Surveys containing as many as 96 sides can be handled as one problem.

(b) The calculation, from graphical representation of the results of field location surveys of required bearings, angles, lengths, and coordinates which meets two requirements. One is prerequisite to computation of final tangent and curve alinement values. The other links individual curve problems to accomplish complete coordination within an entire interchange or other design unit.

(c) The calculation of all tangent and base line intersections.

(d) The calculation of all simple and multi-compound curve data, including transitions. The answers obtained include radius or degree of curve, deflection angle, length of arc and lengths of tangents. Various arrangements are possible for the set-up of each problem. In each case the starting data must be such that a specific solution will result. This corresponds to an ability to lay out the problem graphically.

(e) The location of bull noses between converging or diverging traffic lanes and the calculation of curve and transition data along each side of these bull noses.

(f) The calculation of the coordinates of a stationed point on tangent or on curve. Also the calculation of station and perpendicular offset from tangent or curve for a point whose coordinates are known.

The average computer and tabulation time for individual problems listed under (a) through (f) above is 30 seconds. Loading the program deck into the computer requires about 2 minutes. The one loading will care for any number of problems under the same heading. Punching the cards for a problem requires about 2 minutes on the average. The above steps care for the solution completely between statement of problem on input forms to obtaining useable answers on output forms.

VERTICAL ALINEMENT

Our vertical alinement program is designed to calculate mathematized edges of pavement and final grade line elevations, after the main profile grade line for either a roadway or a bridge has been set by the engineer. Since final profile design requires an accurately stationed line, horizontal alinement calculations are a prerequisite for this entire program.

Four separate types of input forms are in use to accomplish this. A fifth is in process. The following general headings apply:

(a) Calculation of concentric superelevation transitions to give the mathematized profile of a rotating edge of pavement relative to the profile grade line of a roadway, where the rotating edge is concentric with the line upon which the profile grade line is designed, or concentric with the line upon which the profile grade line is projected. In general, this reference line will be the calculated horizontal alinement line with all stationing projected normal to it.

(b) Calculation of pavement widening elevations to give elevations along the flaring edge of a roadway, where the slope of the pavement of the flared area is taken as an extension of the slope of the immediately adjacent lane of the major roadway. The program will give a series of elevations directly along such a flared edge, with the engineer choosing the intervals at which such elevations are desired.

(c) Calculations for parabolic curve fitting taking a series of elevations along any line (such as the flared line described immediately above), and the corresponding stations for each of the respective points, and computing the series of parabolic vertical curves and tangents which fit these points. A combination, therefore, of this program with (b) will give, as a final result, the actual profile of a non-concentric line, relative to and projected upon the same line as the main profile grade line.

(d) Calculation of final grade line elevation to give actual elevations both on vertical tangent and vertical curve, for any profile line which has been mathematized; the elevations being taken at a constant distance interval along this profile line.

(e) In process of coding and to be usable in two weeks is a program designed to calculate all of the vertical geometrics between initial point of diversion and a point opposite the bullnose associated with a ramp entering or leaving a main roadway on tangent or on superelevated curve. The program produces the profile along the outer edge of ramp between the two points mentioned and allows for a break in cross slope of pavement in the warped area concerned.

All programs in the vertical alinement category allow the following maximum complexity of design:

1. Cross section up to and including a triple-crown section.

2. Profile through two successive vertical curves, with or without intermediate tangent.

3. Horizontal alinement up to and including triple-compound curvature. Machine times are comparable to those stated above for horizontal alinement problems.

STRUCTURAL GEOMETRY

The object of the total structural geometry category is the computation of all the precise geometric dimensions necessary to design and to detail bridges. Consistent with a logical sequence, problems in this structural geometry category are undertaken subsequent to finalization of both horizontal and vertical alinements under the two foregoing categories. Two separate types of input forms are in use. A third is in process. The following general headings apply:

(a) Starting with the centerline stations and skew angles of piers and the normal dimensions of the roadway to be carried by the bridge, all dimensions along the skewed centerline of pier are computed. These include horizontal dimensions for tangent, curved or flared layouts between such lines as fascia, curb line, lane lines and centerline of bridge.

(b) The next heading in logical sequence is the calculation of all lengths, bearings and horizontal positional dimensions for each stringer relative to other stringers, roadway configuration and pier dimensions. This problem is in process of being coded and will be in use in 2 to 3 months. This heading involves more instructions (about 10,000) to the computer than any other series of problems under a general heading discussed herein; hence the time required to complete the coding. The problem is being coded so as to provide for up to and including a three-span continuous bridge unit, with directional splices occurring either at pier supports or at points of inflection of stringers. No special restriction will exist as regards parallelism or chord placement of stringers.

(c) The third heading under structural geometry relates to calculation of elevations on the surface of the bridge deck for any combination of horizontal and vertical alinement, including compound horizontal curves and superelevation transitions. The horizontal alinement category and the vertical alinement category as discussed previously each provided for solution of problems in their respective planes only. The complexities of a bridge deck, for which it is desired to compute elevations over stringers and over shoes, are such as to make highly desirable a three-dimensional solution capable of finding elevations at any point on a surface as contrasted to the simpler problem of finding elevations along edges of pavement or lane lines. From the point of view of logic involved this is our most complex program. This program has eliminated the manual effort required to make a tremendous quantity of detailed computations prerequisite to steel detailing.

All programs in this structural geometry category carry forward the complexity of the vertical alinement category as described above and in addition allow for: calculating under heading (a) a maximum of 33 intersections for any one geometry problem including one or more piers; and under heading (c) for either one or two vertical transitions along each edge or curb line on a bridge deck.

DESIGN OF FRAMED BENTS

Before the coding under this heading could be started it was necessary to select the fundamental method of analysis. The slope deflection method was chosen as being the most suited to computer logic with no sacrifice in theoretical rigor. Use of the program of course still requires experienced judgment in the selection of trial sections consistent with the nature of and the loads to be

imposed upon the hyperstatic structure to be designed. The program is currently divided into two phases. The first is completed and being tested in practice to more fully establish the desirable characteristics of the second phase. Within two months these two phases will be intergrated into one unit of computation.

Phase 1 provides for 2- or 3-column bents with or without cantilever overhang and with members having constant cross section along their length. Phase 2 will provide for up to 5 columns and for variable cross sections.

Given the definition of the loading to be carried on the bridge deck, the program positions the loads and computes the maximum moments and shears (in the horizontal member carrying the shoes) at each shoe and at each face of each column. It also computes the maximum force components at each end of each column. Further, and for reinforced concrete bents, the second phase will include calculating required area of steel in beam and in shafts and will verify the concrete stresses in the trial sections.

TYPICAL EXAMPLES

Illustrations have been prepared to provide visual examples of some of the foregoing discussion. For several problems there are shown a pictorial representation, with typical input and output forms, and a brief description of the problem.

TYPICAL EXAMPLES

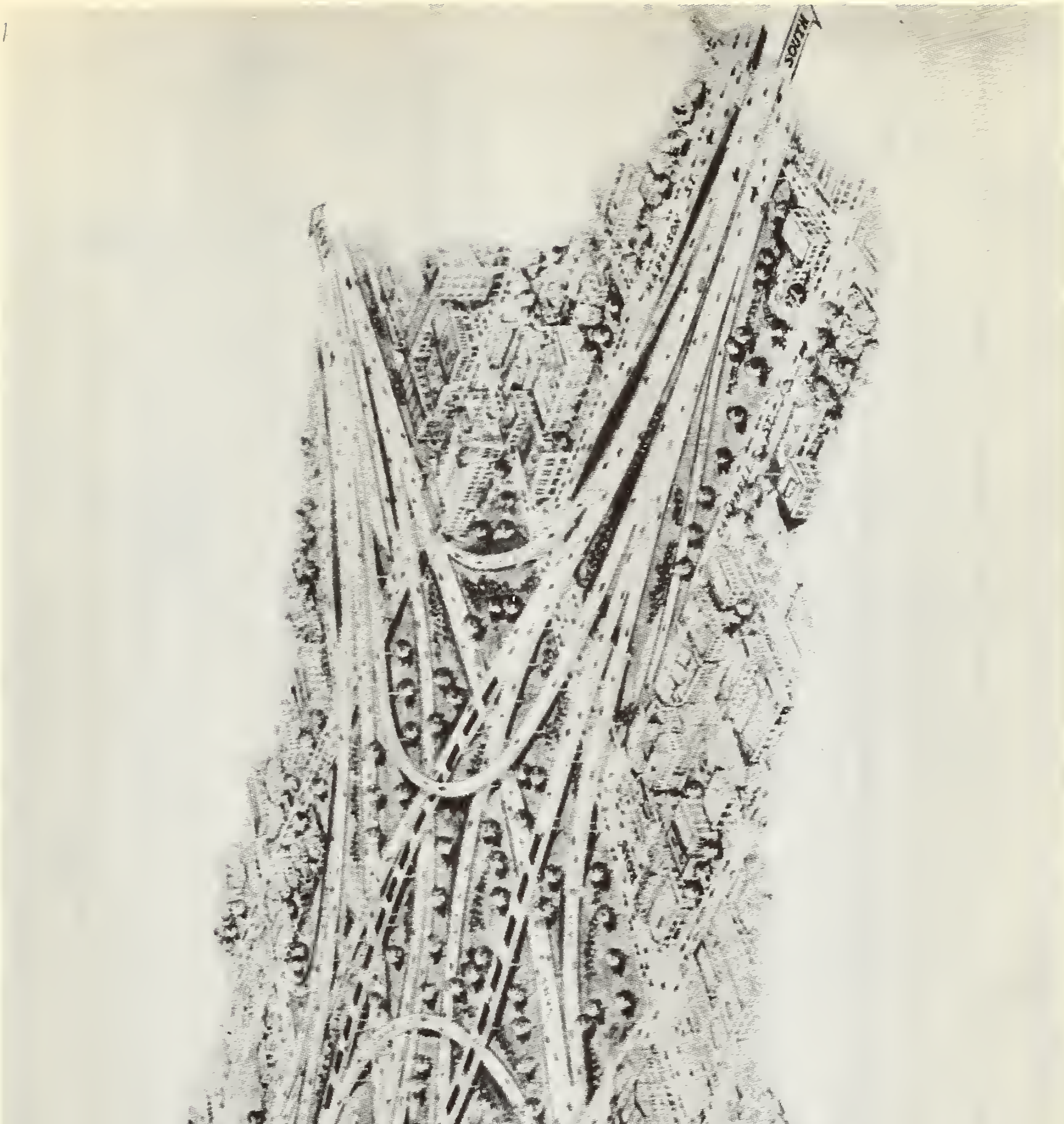

SOUTH
NORTH
WEST

FIGURE 1

The horizontal alinement for the 14th Street Interchange, in Kansas City, was computed virtually entirely by our electronic program. The specific type of problem indicated by the dashed lines on two of the main roadways is illustrated by the input and output forms on the following two pages. The actual size of all forms is 10½ by 16 inches; the letterhead at the top of the form has been omitted for greater clarity in these reproductions.

Computer Code

3	1	0
24	25	26

Coordinates Increase:

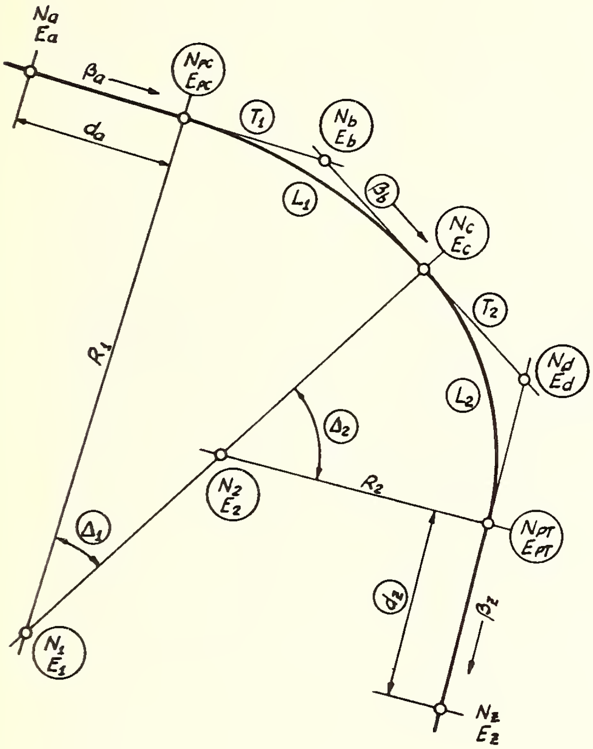
	[ ]	0
N&E	[x]	1
S&E	[ ]	2
N&W	[ ]	3
S&W	[ ]	4
	27	

Direction of Line, Curve or Angle: (facing direction of increasing stations)

	[ ]	0
Right	[x]	1
Left	[ ]	2
	28	

x in 29 for first card

DIAGRAM



NOTE: CIRCLED FIGURES ARE REQUIRED OUTPUT DATA

COORDINATES: ADD TO OUTPUT E 2,000,000

SUB. FROM OUTPUT ______

INPUT DATA

Card No.	Columns	Factor
1	30-31	
	32-41	β_a S 0 5 3° 4 5' 0 0.0" W
		Fill in either
	42-51	D_1^o _ _ _ _ _° _ _' _ _._ _"0
		or
	52-60	R_1 0 0 0 2 0 0 0 0 0
	61-69	N_a 4 3 9 2 3 6.7 3 8
	70-78	E_a 3 6 1 8 0 4.2 8 9
2	30-31	
	32-41	β_2 S 0 8 8° 0 2' 0 0.0" W
		Fill in either
	42-51	D_2^o _ _ _ _ _° _ _' _ _._ _"0
		or
	52-60	R_2 0 0 1 0 2 0 0 0 0
	61-69	N_2 4 3 9 1 2 9.8 1 7
	70-78	E_2 3 6 1 4 3 7.6 1 0
3	30-31	
	32-41	
	42-51	
	52-60	d_a 0 0 0 1 0 0 0 0 0

TAPE TOTAL 20170754552

INPUT FORWARDED TO IBM: DATE: ______

OUTPUT TO BE RETURNED TO: N. Y.

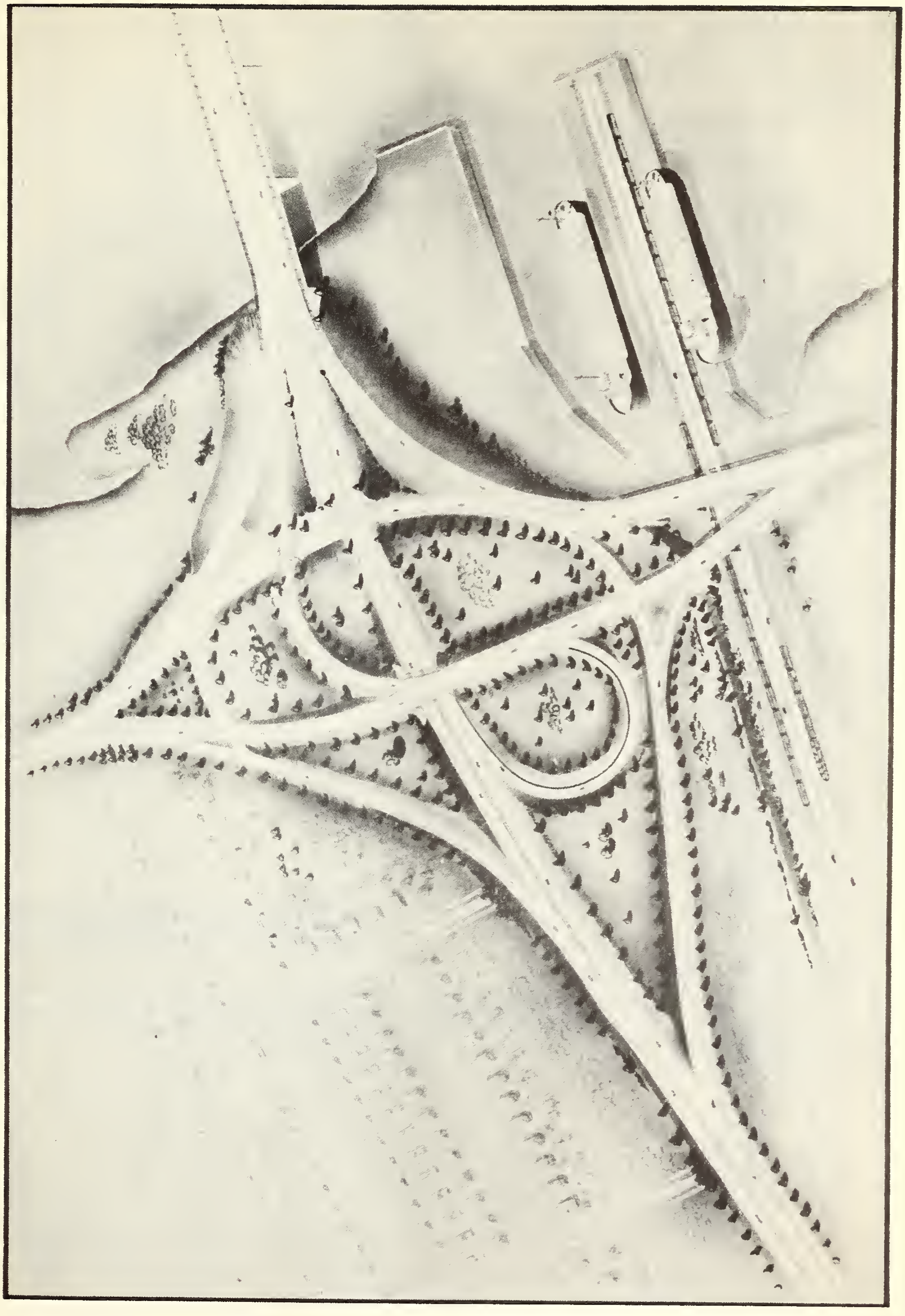
(N.Y. or K.C.)

Sheet ___ of ___

Comp. Code	Coord. Syst.	Direction	Card No.	Bearing β	$\measuredangle$, Δ or $D°$	Coordinates, Radii, Distance		
310	1	1	1	B_a S 53 45 00.0W	$D_1°$	R_1 200.000	N_a 439236.738	E_a 361804.289
310	1	1	2	B_z S 88 02 00.0W	$D_2°$	R_2 1020.000	N_z 439129.817	E_z 361437.610
310	1	1	3			d_a 100.000	d_z	

ABOVE DATA CHECKED AGAINST INPUT BY DATE

		Δ_1 29 13 17.0	T_1 52.136	L_1 102.002	R_1 200.000
		Δ_2 5 03 43.0	T_2 45.086	L_2 90.115	R_2 1020.000
	B_b S 82 58 17.0W	$D°_1$ 28 380.5K4	d_a 100.000	N_{PC} 439177.607	N_b 439146.779
		$D°_2$ 5 370.0K0	d_z 102.498	E_{PC} 361723.645	E_b 361681.600
			N_c 439140.399	N_d 439134.882	N_{PT} 439133.335
			E_c 361629.856	E_d 361585.109	E_{PT} 361540.049
			N_1 439338.896	N_z 439129.817	N_2 440152.734
			E_1 361605.383	E_z 361437.610	E_2 361505.044
		CHECK VALUES	N_1 439338.896	N_z 439129.817	N_2 440152.734
			E_1 361605.383	E_z 361437.612	E_2 361505.045



F I G U R E 2

A complete loop problem occurs frequently on slower speed ramps in interchanges. The horizontal alinement of the loop on the adjacent figure (with computed edge delineated) is solved by the problem illustrated on the next two pages.

Following this is a reproduction of a contract drawing of an alinement data sheet for a complex interchange, showing the large quantity of required information which is received as output data from the horizontal alinement program.

Computer Code

5	2	0
24	25	26

Coordinates Increase:

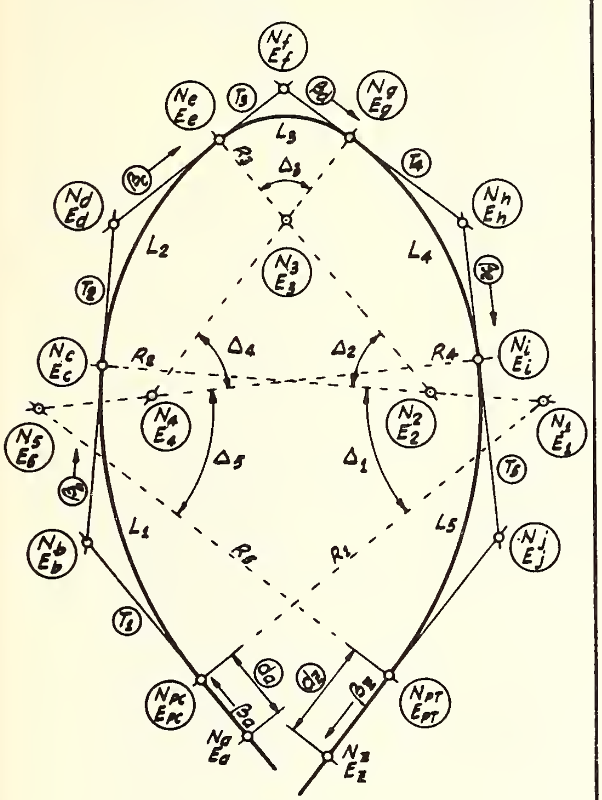
	☐	0
N&E	☒	1
S&E	☐	2
N&W	☐	3
S&W	☐	4
	27	

Direction of Line, Curve or Angle: (facing direction of increasing stations)

	☐	0
Right	☒	1
Left	☐	2
	28	

x in 29 for first card

DIAGRAM



THIS PROBLEM WILL SOLVE FROM THREE THRU TEN CURVES, COMPOUNDING IN THE SAME DIRECTION AS SHOWN. FOR 7 THROUGH 10 CURVE PROBLEMS ONLY, USE SECOND SHEET.

NOTE: CIRCLED FIGURES ARE REQUIRED OUTPUT DATA.

COORDINATES: ADD TO OUTPUT E 2,000,000
SUB. FROM OUTPUT ______

INPUT DATA

Card No.	Columns	Factor	
1	30-31		° ' "
	32-41	β_a	S 0 8 8 0 2 0 0.0 W
	42-51		
	52-60	N_a	4 3 9 1 7 0 2 2 0
	61-69	E_a	3 6 2 2 0 6.2 4 3
	70-78	No. of curves	
2	30-31		° ' "
	32-41	β_z	S 0 8 9 0 0 4 0.0 E
	42-51		
	52-60	N_z	4 3 9 4 7 6.7 6 7
	61-69	E_z	3 6 2 2 1 1.5 3 4

(On all subsequent cards, columns 32-41 are to be punched with zeros.) On all subsequent cards; fill in either D° or R, and all remaining blanks.

Card No.	Columns	Factor	
3	30-31		° ' "
	42-51	Δ_1	0 0 0 6 5 0 0 0 0.0 0
	52-60	R_1	0 0 0 6 1 0.0 0 0
	61-69	D°_1	
	70-78	L_1	0 0 0 0 7 2.7 5 1
4	30-31		° ' "
	42-51	Δ_2	0 0 2 4 1 9 0 0 0.0 0
	52-60	R_2	0 0 0 1 7 5.0 0 0
	61-69	D°_2	
	70-78	L_2	0 0 0 0 7 4.2 7 1
5	30-31		° ' "
	42-51	Δ_3	0 1 2 0 3 9 2 0.0 0
	52-60	R_3	0 0 0 1 5 0.0 0 0
	61-69	D°_3	
	70-78	L_3	0 0 0 3 1 5.8 7 6
6	30-31		° ' "
	42-51	Δ_4	0 0 2 4 1 9 0 0 0.0 0
	52-60	R_4	0 0 0 1 7 5.0 0 0
	61-69	D°_4	
	70-78	L_4	0 0 0 0 7 4.2 7 1
7	30-31		° ' "
	42-51	Δ_5	0 0 0 6 5 0 0 0 0.0 0
	52-60	R_5	0 0 0 6 1 0.0 0 0
	61-69	D°_5	
	70-78	L_5	0 0 0 0 7 2.7 5 1
8	30-31		° ' "
	42-51	Δ_6	0 _ _ _ _ _ _ _ _ 0
	52-60	R_6	
	61-69	D°_6	
	70-78	L_6	

TAPE TOTAL 2 0 4 1 2 7 4 2 9 0 1
(Leave total blank for 7 thru 10 curves)

INPUT FORWARDED TO IBM: DATE: ______
OUTPUT TO BE RETURNED TO: NY
(N.Y. or K.C.)
Sheet ___ of ___

Comp. Code	Coord. Syst.	Direction	Card No.		Bearing β		$\measuredangle$, Δ or D°		Coordinates, Radii, Distance				
520	1	1	1	B_a	S 88 02 00.0W			N_a	439170.220	E_a	362206.243	*	5
520	1	1	2	B_z	S 89 00 40.0E			N_z	439476.767	E_z	362211.534		
520	1	1	3			Δ_1	6 50 00.0	R_1	610.000	D_1°		L_1	72.751
520	1	1	4			Δ_2	24 19 00.0	R_2	175.000	D_2°		L_2	74.271
520	1	1	5			Δ_3	120 39 20.0	R_3	150.000	D_3°		L_3	315.876
520	1	1	6			Δ_4	24 19 00.0	R_4	175.000	D_4°		L_4	74.271
520	1	1	7			Δ_5	6 50 00.0	R_5	610.000	D_5°		L_5	72.751
						Δ_6		R_6		D_6°		L_6	
						Δ_7		R_7		D_7°		L_7	
						Δ_8		R_8		D_8°		L_8	
						Δ_9		R_9		D_9°		L_9	
						Δ_{10}		R_{10}		D_{10}°		L_{10}	

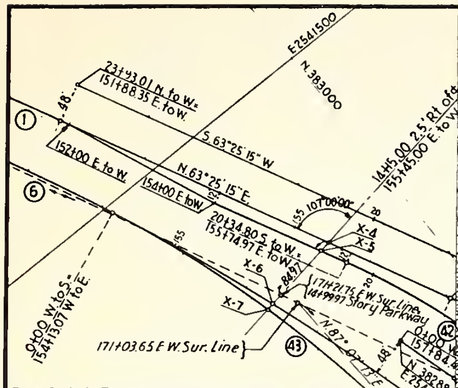
* = Number of curves

NOTE In this case, degree of curve (D°) appears in center "Coordinates, Radii, Distance" column.

ABOVE DATA CHECKED AGAINST INPUT BY DATE

			N_z	439476.767	d_a	63.082	N_{PC}	439168.055
			E_z	362211.534			E_{PC}	362143.198
		CHECK VALUES	N_z	439476.767	d_z	70.992	N_{PT}	439477.992
			E_z	362211.534			E_{PT}	362140.553
			T_1	36.418	N_{01}	439777.696	N_b	439166.805
					E_{01}	362122.264	E_b	362106.801
B_b	N 85 08 00.0W						N_c	439169.895
							E_c	362070.514
			T_2	37.703	N_{02}	439344.264	N_d	439173.094
					E_{02}	362085.361	E_d	362032.947
B_c	N 60 49 00.0W						N_e	439191.478
							E_e	362000.030
			T_3	263.275	N_{03}	439322.437	N_f	439319.852
					E_{03}	362073.171	E_f	361770.174
B_d	N 59 50 20.0E						N_g	439452.130
							E_g	361997.806
			T_4	37.703	N_{04}	439300.822	N_h	439471.073
					E_{04}	362085.732	E_h	362030.404
B_e	N 84 09 20.0E						N_i	439474.912
							E_i	362067.912
			T_5	36.418	N_{05}	438868.083	N_j	439478.621
					E_{05}	362130.027	E_j	362104.140
B_f							N_k	
							E_k	
			T_6		N_{06}		N_l	
					E_{06}		E_l	
B_g							N_m	
							E_m	
			T_7		N_{07}		N_n	
					E_{07}		E_n	
B_h							N_o	
							E_o	
			T_8		N_{08}		N_p	
					E_{08}		E_p	
B_i							N_q	
							E_q	
			T_9		N_{09}		N_r	
					E_{09}		E_r	
B_j							N_s	
							E_s	
			T_{10}		N_{10}		N_t	
					E_{10}		E_t	

B. P. R. DIVISION	STATE	FEDERAL PROJECT	SHEET NO.	TOTAL SHEETS



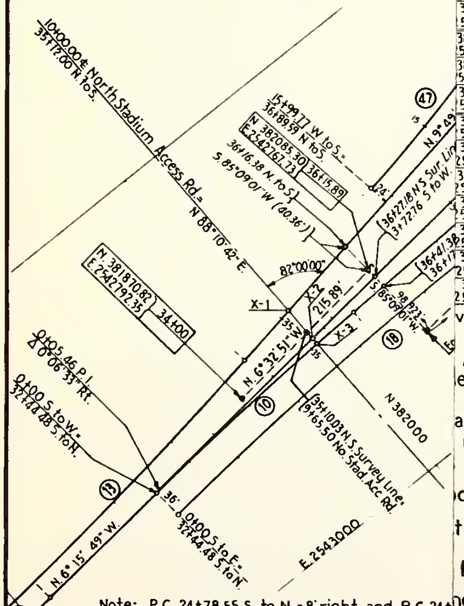
BASE LINE INTERSECTION DATA

No.	Sta.	Sta.	Co-ordinate	Location
X-1	35+12.00 N. to S.	10+00.00 Access Rd.	N. 381979.04 E.2542745.32	Bridge No. 1-W
X-2	2+66.36 S. to W.	9+54.91 Access Rd.	N. 381980.47 E.2542790.39	Bridge No. 1-E.
X-3	35+10.43 S. to N.	9+47.68 Access Rd.	N. 381980.70 E.2542797.62	" "
X-4'	155+45.00 E. to W.	14+15.00 Sty. Pkwy.	N. 382893.37 E.2541702.42	Bridge No. 2-N.
X-5	20+68.45 S. to W.	14+27.55 Sty. Pkwy.	N. 382881.00 E.2541704.51	" "
X-6	156+37.84 W. to E.	15+14.43 Sty. Pkwy.	N. 382795.33 E.2541718.97	Bridge No. 2-S.
X-7	2+23.31 W. to S.	15+23.25 Sty. Pkwy.	N. 382786.63 E.2541720.44	" "
X-8	14+01.90 S. to W.	162+83.84 W. to E.	N. 382947.04 E.2542346.21	Bridge No. 3
X-9	15+59.06 S. to W.	3+63.62 W. to N.	N. 382986.94 E.2542194.61	" "
X-10	42+76.31 N. to S.	10+48.16 S. to W.	N. 382733.31 E.2542622.36	Bridge No. 4 W.
X-11	45+40.84 N. to S.	165+39.20 W. to E.	N. 382996.56 E.2542596.72	" "
X-12	47+27.30 N. to S.	8+07.09 W. to N.	N. 383182.70 E.2542585.95	" "
X-13	48+00.15 N. to S.	164+99.18 E. to W.	N. 383255.50 E.2542583.39	" "
X-14	7+68.81 E. to S.	46+14.61 S. to N.	N. 383084.05 E.2542754.68	Bridge No. 4 E
X-15	8+43.10 E. to S.	166+61.55 W. to E.	N. 383020.29 E.2542716.75	" "
X-16	11+74.59 E. to S.	10+06.70 S. to W.	N. 382699.14 E.2542645.83	" "
X-17	45+58.74 S. to N.	167+02.41 W. to E.	N. 383028.21 E.2542756.83	Bridge No. 5
X-18	48+19.70 S. to N.	166+65.99 E. to W.	N. 383288.98 E.2542746.74	Bridge No. 6
X-19	9+16.54 W. to N.	165+67.49 E. to W.	N. 383271.23 E.2542649.86	" "
X-20	7+73.60 N. to E.	10+73.47 W. to N.	N. 383418.70 E.2542701.30	Bridge No. 7-N.
X-21	8+50.96 N. to E.	48+84.83 S. to N.	N. 383354.03 E.2542743.54	" "
X-22	9+31.82 N. to E.	167+19.58 E. to W.	N. 383296.19 E.2542799.84	" "
X-23	10+82.55 N. to E.	5+42.53 E. to S.	N. 383222.24 E.2542930.21	" "

~CURVE DATA~

ordinate	End Station	Co-ordinate	Center Co-ordinate	Δ	D	R	T	L	Base Line Location
32635.00 41186.00	151+88.35 P.T.	N. 382733.79 E.2541383.46	N. 386149.83 E.2539674.38	6°37'00"	1°30'00"	3819.72	220.80'	441.11'	Lane E to W.
83121.60 42158.59	164+03.26 P.C.C.	N. 383228.18 E.2542491.28	N. 378865.96 E.2543896.90	8°43'17"	1°15'00"	4583.66	349.53'	697.71'	" "
83370.82 42932.16	173+06.04 P.C.C.	N. 383260.81 E.2543382.10	N. 381670.63 E.2542993.29	31°35'51"	3°30'00"	1637.02'	463.19'	902.78'	" "
83225.74 43525.52	176+01.27 P.T.	N. 383183.34 E.2543666.94	N. 377695.19 E.2542021.27	2°57'08"	1°00'00"	5729.58'	147.65'	295.23'	" "
82861.07 44741.67	189+73.91 P.T.	N. 382865.49 E.2544996.32	N. 384502.27 E.2544967.90	17°41'12"	3°30'00"	1637.02'	254.69'	505.33'	" "
82810.00 41653.00	160+32.83 P.T.	N. 382898.36 E.2542099.97	N. 380087.96 E.2542655.54	18°04'24"	2°00'00"	2864.79'	455.62	903.66'	Lane W. to E.
83169.00 43469.00	178+52.74 P.T.	N. 383039.82 E.2543891.97	N. 381353.75 E.2543377.03	28°09'56"	3°15'00"	1762.95'	442.26'	866.64	" "
82844.29 44696.52	189+76.46 P.T.	N. 382849.54 E.2544998.59	N. 384759.11 E.2544965.43	17°58'40"	3°00'00"	1909.86'	302.11'	599.26'	" "
81245.01 42870.61	30+63.94 P.T.	N. 381536.19 E.2542838.65	N. 380880.70 E.2536866.52	5°34'58"	0°57'13"	6008.00'	292.93'	585.39'	Lane S to N
81876.90 42801.26	35+68.78 P.T.	N. 382039.00 E.2542795.00	N. 382215.74 E.2547375.26	4°03'14"	1°15'00"	4583.66	162.22'	324.30'	" "
83660.03 42732.45	55+16.38 P.T.	N. 384038.95 E.2542652.83	N. 383046.39 E.2538167.12	9°39'25"	1°15'00"	4583.66'	387.19'	772.55'	" "
84649.02 42524.64	63+16.80 P.C.C.	N. 384761.32 E.2542491.26	N. 383945.28 E.2539745.16	4°41'00"	2°00'00"	2864.79'	117.15'	234.17'	" "
81429.77 42840.41	34+32.59 P.T.	N. 381900.79 E.2542758.87	N. 380880.70 E.2536866.52	9°08'27"	0°57'29"	5980.00'	478.03'	954.04'	Lane N to S
82991.31 42570.08	50+92.32 P.T.	N. 383547.64 E.2542582.44	N. 383420.38 E.2548310.60	11°05'41"	1°00'00"	5729.58'	556.47'	1109.47'	" "
83952.94 42591.44	57+22.46 P.C.C.	N. 384177.40 E.2542574.37	N. 383829.74 E.2538003.91	5°37'22"	1°15'00"	4583.66	225.09'	449.83'	" "
84376.38 42571.27	61+19.12 P.C.C.	N. 384570.48 E.2542529.01	N. 383961.02 E.2539729.80	7°55'59"	2°00'00"	2864.79	198.64'	396.66	" "
82062.57 42817.09	6+88.78 P.C.C.	N. 382407.31 E.2542831.63	N. 382215.74 E.2547375.26	8°40'40"	1°15'36"	4547.66'	345.05'	688.78'	Ramp S to E.
82615.29 42840.40	11+02.21 P.C.C.	N. 382812.17 E.2542908.00	N. 382346.98 E.2544262.15	16°32'14"	4°00'00"	1432.39'	208.16'	413.43'	" "
83036.10 42984.89	15+31.50 P.C.C.	N. 383081.06 E.2543217.35	N. 382679.26 E.2543295.08	60°06'02"	14°00'00"	409.26'	236.76'	429.29'	" "
83112.51 43379.91	18+60.38 P.C.C.	N. 383096.65 E.2543544.73	N. 381956.00 E.2543434.98	16°26'38"	5°00'00"	1145.92'	165.58'	328.88'	" "
83079.78 43720.03	22+11.42 P.T.	N. 383028.34 E.2543888.47	N. 381353.75 E.2543377.03	11°29'14"	3°16'20"	1750.95'	176.11'	351.05'	" "
83302.75 43223.48	4+87.40 P.C.C.	N. 383239.73 E.2542982.45	N. 382315.86 E.2543224.03	29°14'38"	6°00'00"	954.93'	249.13'	487.40'	Ramp E to S
83190.06 42792.52	8+53.49 P.C.C.	N. 383010.85 E.2542712.38	N. 382843.78 E.2543085.98	51°15'11"	14°00'00"	409.26'	196.31'	366.09'	" "
82807.80 42621.58	12+86.38 P.C.C.	N. 382587.74 E.2542653.97	N. 382698.99 E.2543409.77	32°28'01"	7°30'00"	763.94'	222.43'	432.89'	" "
82516.25 42664.50	14+30.90 P.T.	N. 382445.05 E.2542676.82	N. 383420.38 E.2548310.60	1°26'54"	1°00'08"	5717.58'	72.26'	144.52'	" "
83561.99 42633.22	7+56.06 P.C.C.	N. 383434.40 E.2542693.47	N. 383760.63 E.2543384.26	20°55'45"	7°30'00"	763.94'	141.10'	279.06	Ramp N to E
83231.15 42789.46	11+67.16 P.C.C.	N. 383203.11 E.2543012.48	N. 383609.17 E.2543063.53	57°33'18"	14°00'00"	409.26'	224.78'	411.11'	" "
83194.87 43078.02	12+98.94 P.T.	N. 383198.00 E.2543144.00	N. 383961.08 E.2543107.78	9°53'00"	7°30'00	763.94	66.05	131.78'	" "
83214.20 43485.33	18+57.37 P.T.	N. 383149.63 E.2543696.77	N. 381931.91 E.2543324.87	19°42'03"	4°30'00"	1273.24'	221.08'	437.80'	" "
83373.21 43200.85	6+52.35 P.C.C.	N. 383439.35 E.2543064.00	N. 385158.94 E.2543895.00	9°06'02"	3°00'00"	1909.86	151.99	303.35	Ramp E to N
83554.51 42825.69	11+51.17 P.C.C.	N. 383807.86 E.2542749.11	N. 383982.38 E.2543326.42	47°23'16"	9°30'00"	603.11'	264.67'	498.82'	" "
83926.46 42713.25	13+98.83 P.T.	N. 384047.72 E.2542687.77	N. 384636.82 E.2545491.34	4°57'11"	2°00'00"	2864.79'	123.91'	247.66'	" "
84532.53 42500.42	0+62.00 P.C.C.	N. 384502.10 E.2542506.36	N. 383961.02 E.2539729.80	1°15'21"	2°01'32"	2828.79	31.00	62.00	Ramp N to W
84023.08 42599.70	10+17.61 P.C.C.	N. 383558.01 E.2542451.81	N. 384136.79 E.2540631.76	28°40'06"	3°00'00"	1909.86'	488.03'	955.61'	" "
83367.60 42391.26	14+03.49 P.C.C.	N. 383251.00 E.2542229.00	N. 383740.78 E.2541877.06	36°39'31"	9°30'00"	603.11'	199.80'	385.88'	" "
83117.65 42043.43	18+59.55 P.T.	N. 383015.41 E.2541839.07	N. 385577.44 E.2540557.26	9°07'16"	2°00'00"	2864.79'	228.51'	456.06'	" "
83039.83 42377.22	6+62.57 P.C.C.	N. 383093.50 E.2542473.00	N. 383926.53 E.2542006.15	13°07'01"	6°00'00"	954.93'	109.79'	218.62'	Ramp W to N.
83196.60 42656.96	10+57.86 P.C.C.	N. 383403.38 E.2542698.36	N. 383493.36 E.2542248.91	49°24'42"	12°30'00"	458.37'	210.88	395.29'	" "
83561.35 42729.99	13+77.07 P.C.C.	N. 383720.95 E.2542708.04	N. 383590.84 E.2541762.01	19°09'10"	6°00'00"	954.93'	161.11'	319.21'	" "
83094.78 42670.23	17+49.40 P.C.C.	N. 382983.99 E.2542005.00	N. 382356.03 E.2542109.58	93°18'03"	9°00'00"	636.62'	674.39'	1036.68'	Ramp S to W
382960.38 2541863.18	20+34.80 P.T.	N. 382896.05 E.2541734.60	N. 382042.04 E.2542161.87	17°07'27"	6°00'00"	954.93'	143.77'	285.40'	" "
382818.22 2541749.39	5+17.45 P.C.C.	N. 382831.36 E.2542010.63	N. 381400.78 E.2542082.60	20°41'53"	4°00'00"	1432.39'	261.58'	517.45'	Ramp W to S
382839.15 2542165.42	8+23.26 P.C.C.	N. 382786.00 E.2542311.00	N. 382068.38 E.2542049.01	22°56'09"	7°30'00"	763.94'	154.98'	305.81'	" "
382750.73 2542407.60	10+24.76 P.C.C.	N. 382673.99 E.2542476.06	N. 382401.56 E.2542170.65	28°12'36"	14°00'00"	409.26'	102.84'	201.50'	" "
382540.78 2542594.89	13+75.50 P.C.C.	N. 382368.70 E.2542642.38	N. 382165.46 E.2541905.97	26°18'18"	7°30'00"	763.94'	178.51'	350.74'	" "
382260.52 2542672.24	15+99.77 P.T.	N. 382149.93 E.2542691.38	N. 381758.98 E.2540433.14	5°36'25"	2°30'00"	2291.83'	112.23'	224.28'	" "

ve No. 16 Ø-3°00'00"



Note: P.C. 24+78.55 S. to N. = 8' right and P.C. 24+
N. to S. = 20' left of Sta. 24+78.55 ℄ South
44th Street Expressway. Project U-572

All Stationing,
e Grades are

ane Co-ordinate
(South Zone)

oints

tion points

points

ngents to Survey Traverse

NO.	DATE	REVISION	BY

MILWAUKEE COUNTY
EXPRESSWAY COMMISSION

STADIUM INTERCHANGE

ALIGNMENT PLAN

SCALE 1" = 100'
MADE V.F.D. DATE 4-4-57
TRCD V.F.D. DATE 6-21-57
CKD R.W.K. DATE 7-15-57

HOWARD, NEEDLES, TAMMEN & BERGENDOFF
CONSULTING ENGINEERS
KANSAS CITY NEW YORK
SHEET

Comp. Code	Coord. Syst.	Direc-tion	Card No.		Bearing β		$\measuredangle$, Δ or $D°$		Coordinates, Radii, Distance				
520	1	1	1	B_a	S 88 02 00.0W			N_a	439170.220	E_a	362206.243	*	5
520	1	1	2	B_z	S 89 00 40.0E			N_z	439476.767	E_z	362211.534		
520	1	1	3			Δ_1	6 50 00.0	R_1	610.000	$D_1°$		L_1	72.751
520	1	1	4			Δ_2	24 19 00.0	R_2	175.000	$D_2°$		L_2	74.271
520	1	1	5			Δ_3	120 39 20.0	R_3	150.000	$D_3°$		L_3	315.876
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520	1	1	7			Δ_5	6 50 00.0	R_5	610.000	$D_5°$		L_5	72.751
						Δ_6		R_6		$D_6°$		L_6	
						Δ_7		R_7		$D_7°$		L_7	
						Δ_8		R_8		$D_8°$		L_8	
						Δ_9		R_9		$D_9°$		L_9	
						Δ_{10}		R_{10}		$D_{10}°$		L_{10}	

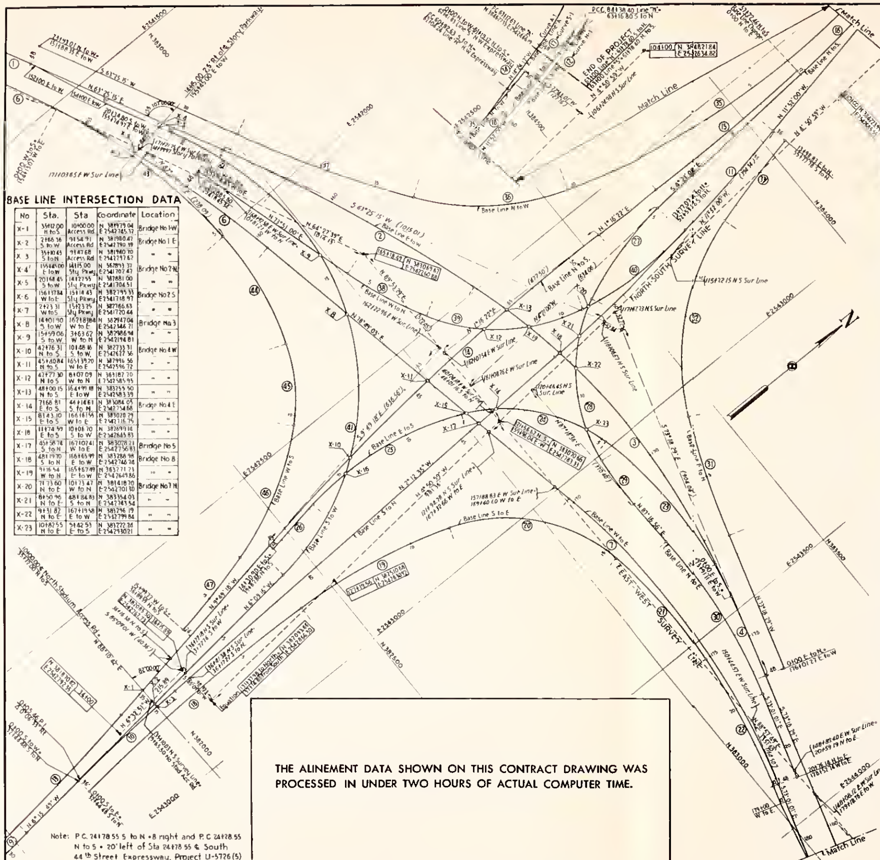
* = Number of curves

NOTE In this case, degree of curve ($D°$) appears in center "Coordinates, Radii, Distance" column.

ABOVE DATA CHECKED AGAINST INPUT BY DATE

			N_z	439476.767	d_a	63.082	N_{PC}	439168.055
			E_z	362211.534			E_{PC}	362143.198
		CHECK VALUES {	N_z	439476.767	d_z	70.992	N_{PT}	439477.992
			E_z	362211.534			E_{PT}	362140.553
			T_1	36.418	N_{01}	439777.696	N_b	439166.805
					E_{01}	362122.264	E_b	362106.801
B_b	N 85 08 00.0W						N_c	439169.895
							E_c	362070.514
			T_2	37.703	N_{02}	439344.264	N_d	439173.094
					E_{02}	362085.361	E_d	362032.947
B_c	N 60 49 00.0W						N_e	439191.478
							E_e	362000.030
			T_3	263.275	N_{03}	439322.437	N_f	439319.852
					E_{03}	362073.171	E_f	361770.174
B_d	N 59 50 20.0E						N_g	439452.130
							E_g	361997.806
			T_4	37.703	N_{04}	439300.822	N_h	439471.073
					E_{04}	362085.732	E_h	362030.404
B_e	N 84 09 20.0E						N_i	439474.912
							E_i	362067.912
			T_5	36.418	N_{05}	438868.083	N_j	439478.621
					E_{05}	362130.027	E_j	362104.140
B_f							N_k	
							E_k	
			T_6		N_{06}		N_l	
					E_{06}		E_l	
B_g							N_m	
							E_m	
			T_7		N_{07}		N_n	
					E_{07}		E_n	
B_h							N_o	
							E_o	
			T_8		N_{08}		N_p	
					E_{08}		E_p	
B_i							N_q	
							E_q	
			T_9		N_{09}		N_r	
					E_{09}		E_r	
B_j							N_s	
							E_s	
			T_{10}		N_{10}		N_t	
					E_{10}		E_t	

B. P. R. DIVISION	STATE	FEDERAL PROJECT	SHEET NO.	TOTAL SHEETS



BASE LINE INTERSECTION DATA

No	Sta.	Sta	Co-ordinate	Location
X-1	35+17.00 N to S	10+00.00 Access Rd	N 381979.04 E 2542745.32	Bridge No 1 W
X-2	2+68.36 S to W	9+54.91 Access Rd	N 381980.47 E 2542790.39	Bridge No 1 E
X-3	35+10.45 S to N	9+47.68 Access Rd	N 381980.70 E 2542797.62	" "
X-4'	155+45.00 E to W	14+15.00 Sty Pkwy	N 382893.37 E 2541702.47	Bridge No 2 N
X-5	20+64.45 S to W	14+27.55 Sty Pkwy	N 382881.00 E 2541704.51	" "
X-6	156+37.84 W to E	15+14.43 Sty Pkwy	N 382795.33 E 2541718.97	Bridge No 2 S
X-7	2+23.31 W to S	15+23.25 Sty Pkwy	N 382786.63 E 2541720.44	" "
X-8	14+01.90 S to W	167+83.04 W to E	N 382947.04 E 2542146.21	Bridge No 3
X-9	15+59.06 S to W	3+63.62 W to N	N 382986.94 E 2542194.81	" "
X-10	42+76.31 N to S	10+48.16 S to W	N 382733.31 E 2542677.56	Bridge No 4 W
X-11	45+40.84 N to S	165+39.20 W to E	N 382996.56 E 2542596.72	" "
X-12	47+77.30 N to S	8+07.09 W to N	N 383187.70 E 2542585.95	" "
X-13	48+00.15 N to S	164+99.18 E to W	N 383255.50 E 2542583.39	" "
X-14	7+68.81 E to S	44+14.61 S to N	N 383084.05 E 2542754.68	Bridge No 4 E
X-15	8+43.10 E to S	166+61.56 W to E	N 383020.29 E 2542716.75	" "
X-16	11+74.59 E to S	10+06.70 S to W	N 382699.14 E 2542645.83	" "
X-17	45+58.74 S to N	167+07.41 W to E	N 383028.21 E 2542756.83	Bridge No 5
X-18	48+19.70 S to N	166+65.99 E to W	N 383288.98 E 2542746.74	Bridge No 8
X-19	9+16.54 W to N	165+67.49 E to W	N 383271.23 E 2542649.86	" "
X-20	7+73.60 N to E	10+73.47 W to N	N 381418.70 E 2542701.30	Bridge No 7 N
X-21	8+50.96 N to E	48+84.83 S to N	N 383354.03 E 2542743.54	" "
X-22	9+31.82 N to E	167+19.58 E to W	N 383296.19 E 2542799.84	" "
X-23	10+82.55 N to E	5+42.53 E to S	N 383272.24 E 2542930.21	" "

Note: P.C. 24+78.55 S to N • 8 right and P.C. 24+78.55 N to S • 20' left of Sta 24+78.55 ℄ South 44th Street Expressway, Project U-5726(5)

THE ALINEMENT DATA SHOWN ON THIS CONTRACT DRAWING WAS PROCESSED IN UNDER TWO HOURS OF ACTUAL COMPUTER TIME.

~CURVE DATA~

Curve No.	Beginning Station	Beginning Coordinate	P.I. Station	P.I. Coordinate	End Station	End Co-ordinate	Center Co-ordinate	Δ	D	R	T	L	Base Line Location
1	147+47.24 P.C.	N 382559.62 E 2540978.47	149+68.04	N 382635.00 E 2541186.00	151+88.35 P.T.	N 382733.79 E 2541383.46	N 386149.83 E 2539674.38	6°37'00"	1°30'00"	3819.72	220.80'	441.11'	Lane E to W
2	157+05.55 P.C.	N 382965.21 E 2541846.01	160+55.08	N 383121.60 E 2542158.59	164+03.26 P.C.C.	N 383220.78 E 2542491.28	N 378865.96 E 2543896.90	8°43'17"	1°15'00"	4583.66'	349.53'	697.71'	" "
3	164+03.26 P.C.C.	N 383220.78 E 2542491.28	168+66.45	N 383370.82 E 2542932.16	173+06.04 P.C.C.	N 383260.81 E 2543382.10	N 381670.63 E 2542993.29	31°35'51"	3°30'00"	1637.02'	463.19'	902.78'	" "
4	173+06.04 P.C.C.	N 383260.81 E 2543382.10	174+53.69	N 383225.74 E 2543525.52	176+01.27 P.T.	N 383183.34 E 2543666.94	N 377695.19 E 2542021.27	2°57'08"	1°00'00"	5729.58	147.65'	295.23'	" "
5	184+68.58 P.C.	N 382934.22 E 2544497.71	187+23.27	N 382861.07 E 2544741.67	189+73.91 P.T.	N 382865.49 E 2544996.32	N 384502.27 E 2544967.90	17°41'12"	3°30'00"	1637.02'	254.69'	505.33'	" "
6	151+29.17 P.C.	N 382587.34 E 2541255.50	155+84.79	N 382810.00 E 2541653.00	160+32.83 P.T.	N 382898.36 E 2542099.97	N 380087.98 E 2542655.54	18°04'24"	2°00'00"	2864.79	455.62	903.66'	Lane W to E
7	169+66.10 P.C.	N 383083.73 E 2543035.14	174+28.36	N 383154.00 E 2543469.00	178+52.74 P.T.	N 383039.87 E 2543891.97	N 381353.75 E 2543377.03	28°09'56"	3°15'00"	1762.95	442.76'	866.64	" "
8	183+77.20 P.C.	N 382932.54 E 2544407.58	186+79.31	N 382844.29 E 2544696.52	189+7[illegible] P.T.	N 382849.54 E 2544998.59	N 384759.11 E 2544965.43	17°58'40"	3°00'00"	1909.86'	302.11'	599.26'	" "
9	[illegible] P.C.	N 380952.11 E 2542874.09	27+71.48	N [illegible] E 2542870.61	[illegible] P.T.	N [illegible] E 2542838.65	N 380880.70 E 2536866.57	5°34'58"	0°57'13"	6008.00'	292.93	585.39'	Lane S to N
10	[illegible] P.C.	N [illegible] E 2542818.95	34+06.70	[illegible] E 2542801.26	[illegible] P.T.	N [illegible] E 2542795.00	N [illegible] E 2547375.26	4°03'14"	1°15'00"	4583.66	182.22	324.30	- -
11	48+03.83 P.C.	N 383273.13 E 2542747.38	51+91.02	N 383660.03 E 2542732.45	55+76.38 P.T.	N 384038.95 E 2542657.63	N 383096.39 E 2538147.12	9°39'25"	1°15'00"	4583.66'	387.19'	772.55'	" "
12	60+87.63 P.C.	N 384534.38 E 2542548.73	61+99.78	N 384649.02 E 2542524.64	63+16.80 P.C.C.	N 384761.32 E 2542491.76	N 383945.28 E 2539745.16	4°41'00"	2°00'00"	2864.79'	117.15	234.17'	" "
13	24+78.55 P.C.	N 380951.77 E 2542846.09	29+56.38	N 381429.77 E 2542840.41	34+32.59 P.T.	N 381900.79 E 2542758.87	N 380880.70 E 2536866.52	9°08'27"	0°57'29"	5980.00'	478.03	954.06'	Lane N to S
14	39+87.86 P.C.	N 382443.00 E 2542665.00	45+39.32	N 382991.31 E 2542570.08	50+97.32 P.T.	N 383547.64 E 2542582.44	N 383470.38 E 2548310.60	11°05'41"	1°00'00"	5729.58'	556.47'	1109.47'	" "
15	52+12.63 P.C.	N 383727.90 E 2542586.44	54+97.72	N 383952.94 E 2542591.44	57+22.46 P.C.C.	N 384177.40 E 2542574.37	N 383829.74 E 2538003.91	5°37'22"	1°15'00"	4583.66	225.09'	449.83'	" "
16*	57+22.46 P.C.C.	N 384178.31 E 2542586.33	59+21.10	N 384376.38 E 2542571.77	61+19.12 P.C.C.	N 384570.46 E 2542529.01	N 383981.02 E 2539729.80	7°55'59"	2°00'00"	2864.79	198.64'	396.66	" "
18	0+00.00 P.C.	N 381719.58 E 2542854.74	3+45.05	N 382062.57 E 2542817.09	6+88.78 P.C.C.	N 382407.31 E 2542831.63	N 382215.74 E 2547375.26	8°40'40"	1°15'36"	4547.66'	345.05	688.78'	Ramp S to E
19	6+88.78 P.C.C.	N 382407.31 E 2542831.63	8+98.94	N 382615.29 E 2542840.40	11+02.21 P.C.C.	N 382812.17 E 2542908.00	N 382346.98 E 2544262.75	18°32'14"	4°00'00"	1432.39'	208.18'	413.43'	" "
20	11+02.21 P.C.C.	N 382812.17 E 2542908.00	13+38.97	N 383036.10 E 2542984.89	15+31.50 P.C.C.	N 383081.06 E 2543217.35	N 382679.26 E 2543295.08	60°06'02"	14°00'00"	409.26'	236.78'	429.29'	" "
21	15+31.50 P.C.C.	N 383081.06 E 2543217.35	16+92.08	N 383112.51 E 2543379.91	18+60.38 P.C.C.	N 383096.65 E 2543544.73	N 381956.00 E 2543434.98	16°28'38"	5°00'00"	1145.92'	165.58'	328.88'	" "
22	18+60.38 P.C.C.	N 383096.65 E 2543544.73	20+36.49	N 383079.74 E 2543720.03	22+11.42 P.T.	N 383028.34 E 2543888.47	N 381353.79 E 2543177.03	11°29'14"	3°16'20"	1238.95'	176.11'	351.05'	" "
23	0+00.00 P.C.C.	N 383240.00 E 2543464.59	2+49.13	N 383307.75 E 2543227.48	4+87.40 P.C.C.	N 383239.73 E 2542982.45	N 382315.86 E 2543224.03	29°14'38"	6°00'00"	954.93'	249.13'	487.40'	Ramp E to S
24	4+87.40 P.C.C.	N 383239.73 E 2542982.45	6+83.71	N 383190.06 E 2542792.57	8+53.49 P.C.C.	N 383010.85 E 2542712.38	N 382843.78 E 2543065.98	51°15'11"	14°00'00"	409.26'	196.31'	388.09'	" "
25	6+53.49 P.C.C.	N 383010.65 E 2542712.38	10+75.92	N 382807.80 E 2542621.56	12+86.38 P.C.C.	N 382587.74 E 2542653.97	N 382698.99 E 2543409.17	32°28'01"	7°30'00"	763.94'	222.43'	432.89'	" "
26	12+86.38 P.C.C.	N 382587.74 E 2542653.97	13+58.64	N 382516.25 E 2542664.50	14+30.90 P.T.	N 382445.05 E 2542676.82	N 383420.38 E 2548310.60	1°26'54"	1°00'08"	5717.58	72.28'	144.52'	" "
27	4+77.00 P.C.	N 383702.68 E 2542672.51	8+18.10	N 383561.99 E 2542633.72	7+56.06 P.C.C.	N 383434.40 E 2542693.47	N 383760.63 E 2543384.28	20°55'45"	7°30'00"	763.94	141.10'	279.08	Ramp N to E
28	7+56.06 P.C.C.	N 383434.40 E 2542693.47	9+80.84	N 383231.15 E 2542789.46	11+67.16 P.C.C.	N 383203.11 E 2543012.48	N 383609.17 E 2543063.53	57°33'18"	14°00'00"	409.68'	224.78'	411.11'	" "
29	11+67.16 P.C.C.	N 383203.11 E 2543012.48	12+33.22	N 383194.87 E 2543078.07	12+98.94 P.T.	N 383196.00 E 2543144.00	N 383961.08 E 2543107.78	9°53'00"	7°30'00	763.94	66.05	131.78'	" "
30	14+19.58 P.C.	N 383203.72 E 2543264.50	16+40.68	N 383214.20 E 2543485.33	16+57.37 P.T.	N 383149.83 E 2543696.77	N 381931.91 E 2543324.87	19°47'03"	4°30'00"	1273.24'	221.08'	437.40'	" "
31	3+49.00 P.C.	N 383329.56 E 2543346.44	5+00.99	N 383373.21 E 2543200.85	6+52.35 P.C.C.	N 383439.35 E 2543064.00	N 385158.94 E 2543895.00	9°08'02"	3°00'00"	1909.86	151.99	303.35	Ramp E to N
32	6+52.35 P.C.C.	N 383439.35 E 2543064.00	9+12.07	N 383554.51 E 2542825.69	11+51.17 P.C.C.	N 383807.86 E 2542749.11	N 383982.38 E 2543326.42	47°23'18"	9°30'00"	603.11'	264.67'	498.82'	" "
33	11+51.17 P.C.C.	N 383807.86 E 2542749.11	12+75.08	N 383926.46 E 2542713.75	13+98.83 P.T.	N 384047.72 E 2542687.77	N 384636.82 E 2545491.34	4°57'11"	2°00'00"	2864.79	123.91'	247.66'	" "
34	0+00.00 P.C.	N 384567.82 E 2542493.83	0+31.00	N 384537.53 E 2542500.42	0+62.00 P.C.C.	N 384507.10 E 2542506.36	N 383961.02 E 2539729.80	1°15'21"	2°01'32"	2828.79	31.00	82.00	Ramp N to W
35	0+62.00 P.C.C.	N 384507.10 E 2542506.36	5+50.03	N 384023.08 E 2542599.70	10+17.61 P.C.C.	N 383558.01 E 2542451.81	N 384136.79 E 2540631.76	28°40'06"	3°00'00"	1909.88	488.03'	955.61'	" "
36	10+17.61 P.C.C.	N 383558.01 E 2542451.81	12+17.41	N 383367.60 E 2542391.76	14+03.49 P.C.C.	N 383251.00 E 2542229.00	N 383740.78 E 2541877.06	36°39'31"	9°30'00"	603.11'	199.80	385.88'	" "
37	14+03.49 P.C.C.	N 383251.00 E 2542229.00	16+32.00	N 383117.65 E 2542043.43	18+59.55 P.T.	N 383015.41 E 2541839.07	N 385577.44 E 2540557.26	9°07'16"	2°00'00"	2864.79'	228.51'	456.06'	" "
38	4+43.95 P.C.	N 383009.29 E 2542271.77	5+53.74	N 383019.83 E 2542377.22	6+62.57 P.C.C.	N 383093.50 E 2542473.00	N 383926.53 E 2542006.15	13°07'01"	6°00'00"	954.93'	109.79	218.62'	Ramp W to N
39	6+62.57 P.C.C.	N 383093.50 E 2542473.00	8+73.45	N 383196.60 E 2542656.96	10+57.86 P.C.C.	N 383403.38 E 2542698.36	N 383493.36 E 2542248.91	49°24'42"	12°30'00"	458.37'	210.88	395.29'	" "
40	10+57.86 P.C.C.	N 383403.38 E 2542698.76	12+18.97	N 383561.35 E 2542729.99	13+77.07 P.C.C.	N 383720.95 E 2542708.04	N 383590.84 E 2541762.01	19°09'10"	6°00'00"	954.93'	161.11'	319.21'	" "
41	7+12.73 P.C.	N 382424.27 E 2542742.53	13+87.12	N 383094.78 E 2542670.23	17+49.40 P.C.C.	N 382983.99 E 2542005.00	N 382356.03 E 2542109.58	93°18'03"	9°00'00"	636.62'	674.39'	1036.68'	Ramp S to W
42	17+49.40 P.C.C.	N 382983.99 E 2542005.00	18+93.18	N 382960.38 E 2541863.18	20+34.60 P.T.	N 382896.05 E 2541734.60	N 382047.04 E 2542161.87	17°07'27"	6°00'00"	954.93'	143.77	285.40'	" "
43	0+00.00 P.C.	N 382713.59 E 2541509.65	2+61.58	N 382816.22 E 2541749.29	5+17.45 P.C.C.	N 382831.36 E 2542010.63	N 381400.78 E 2542087.60	20°41'53"	4°00'00"	1432.39'	261.58	517.45'	Ramp W to S
44	5+17.45 P.C.C.	N 382831.36 E 2542010.63	6+72.43	N 382839.15 E 2542165.42	8+23.26 P.C.C.	N 382786.00 E 2542311.00	N 382068.38 E 2542049.01	22°56'09"	7°30'00"	763.94'	154.98'	305.81'	" "
45	8+23.26 P.C.C.	N 382786.00 E 2542311.00	9+26.10	N 382750.73 E 2542407.60	10+24.78 P.C.C.	N 382673.99 E 2542476.06	N 382401.56 E 2542170.65	28°12'36"	14°00'00"	409.26'	102.84'	201.50'	" "
46	10+24.78 P.C.C.	N 382673.99 E 2542476.06	12+03.28	N 382540.78 E 2542594.89	13+75.50 P.C.C.	N 382368.70 E 2542642.38	N 382165.46 E 2541905.97	26°18'18"	7°30'00"	763.94'	178.51'	350.74'	" "
47	13+75.50 P.C.C.	N 382368.70 E 2542642.38	14+87.72	N 382260.52 E 2542672.24	15+99.77 P.T.	N 382149.93 E 2542691.38	N 381758.98 E 2540433.14	5°38'25"	2°30'00"	2291.83	112.23'	224.28'	" "

* Curve No 17 Beginning • End Curve No 18 Δ • 3°00'00"

Note:

Only Base Lines are shown. All Stationing, Horizontal Curvature, and Profile Grades are computed along the Base Lines.

500 foot Grid is based on the Plane Co-ordinate System for the State of Wisconsin (South Zone)

~LEGEND~

- Base line curve points
- Base line intersection points
- Survey Traverse points
- Tie from Base Line tangents to Survey Traverse

NO.	DATE	REVISION	BY

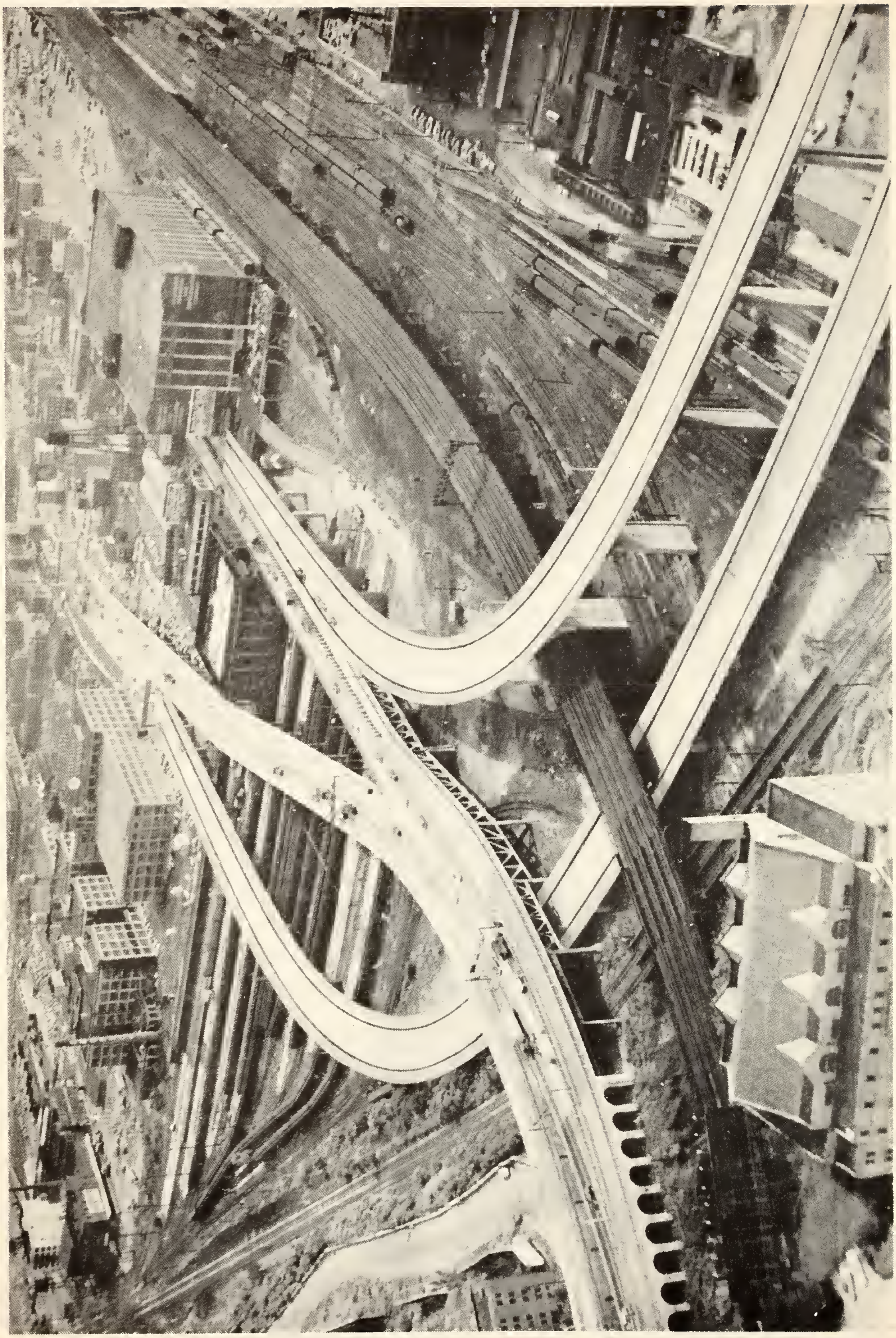
MILWAUKEE COUNTY EXPRESSWAY COMMISSION

STADIUM INTERCHANGE

ALIGNMENT PLAN

SCALE 1" = 100'
MADE V.F.D. DATE 4-4-57
TRCD V.F.D. DATE [illegible]
CKD R.W.K. DATE 7-18-57

HOWARD, NEEDLES, TAMMEN & BERGENDOFF
CONSULTING ENGINEERS
KANSAS CITY NEW YORK



F I G U R E 3

Structures in urban and industrial areas frequently must be designed for curvatures requiring superelevation of the roadways. The computation of deck edges, delineated on the photogragh, is illustrated by the input and output forms on the following two pages.

The resulting edge profiles are theoretically correct and aesthetically pleasing, since the program develops the ideal cubic equation of a rotating edge and reduces it to compounding parabolic vertical curves, eliminating any unnecessary reverse vertical curves in the fascia of the structure.

The calculation of final grade line elevations, for either main profile grade lines or rotating edges, is illustrated by the succeeding input and output forms. Note that the output data gives, in addition to the grade elevation, the slope of the tangent to the vertical curve at every point.

NOTE: Duplicate Columns 1 thru 20 on all following cards.

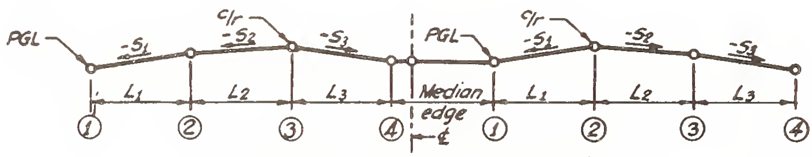
MAIN PROFILE GRADE LINE

Card No.	Station of PVI	Elevation of PVI	G_1	G_2	LVC	
21	22-30	31-37	38-42	43-47	48-54	
1	13+50000	50000	+ 2000	− 3000	600000	Curve #1
2	26+50000	11000	− 3000	+ 2500	500000	Curve #2

NOTE: If line is tangent, fill in zeros for G_2 and LVC in first line; omit entire second line.
For G_1 G_2 and S_1 S_2 S_3 S_s fill in either plus or minus sign in box. ($\pm$ S_s = Crosslope at full superelevation)

CROSS-SECTIONS

Card No.	Crown Line At	PGL	L_1	L_2	L_3	Sta. 1 (Begin Transition)	S_s
21	22	23	24-28	29-33	34-38	39-47	48-52
3	1,2,3 or 4 2	8	12000	12000	12000	10+00000	+ 8000
		Super to Norm. 8 Norm. to Super 9	S_1	S_2	S_3	Sta. 2 (End Transition)	
4	0	8 or 9 9	− 1000	− 4000	− 4000	30+00000	00000



TYPICAL Normal Cross-Section.

STATIONS: ADD TO OUTPUT ________
SUB. FROM OUTPUT ________
ELEVATIONS: ADD TO OUTPUT ________
SUB. FROM OUTPUT ________

INPUT FORWARDED: DATE: ________
OUTPUT TO BE RETURNED TO: N. Y.
(K.C. or N.Y.)

Sheet ___ of ___

INPUT DATA

3 1	13 50.000	50.000	2.000	3.000-	600.000
3 2	26 50.000	11.000	3.000-	2.500	500.000
3 3 2 8	12.000	12.000	12.000	10 00.000	8.000
3 4 0 9	4.000-	2.000	4.000-	30 00.000	

OUTPUT DATA

	Station of PVI	Elevation PVI	G_1	G_2	LVC	
3 5	10 25.000	43.259	2.000	2.015	50.000	1
3 5	13 50.000	49.810	2.015	2.797-	600.000	2
3 5	18 25.000	36.523	2.797-	2.688-	350.000	3
3 5	22 00.000	26.443	2.688-	2.812-	400.000	4
3 5	26 50.000	13.786	2.812-	2.531	500.000	5
3 5	29 50.000	21.379	2.531	2.500	100.000	6
3 6	10 00.000					S1
3 6	13 92.525					H1
3 6	20 39.288					H2
3 6	30 00.000					S2
3 6	13 92.525	45.973				X

NOTE: Duplicate Columns 1 thru 20 on all following cards.

PROFILE GRADE LINE

Card No.	Station of PVI	Elevation of PVI	G_1	G_2	LVC	
21	22-30	31-37	38-42	43-47	48-54	
1	0 0 0 4+0 0.0 0 0	0 3 5 7.3 0 0	− 0 1.9 5 0	+ 0 5 0 0 0	0 4 0 0 0 0 0	Curve #1
2	0 0 1 0+0 0.0 0 0	3 8 7.3 0 0	+ 0 5 0 0 0	− 0 5 0 0 0	0 5 0 0 0 0 0	Curve #2

NOTE: If line is tangent, fill in zeros for G2 and LVC in first line; omit entire second line.

Card Type	Beginning Sta.	End Sta.	Constant D*
21	22-30	31-39	40-46
6	0 0 0 1+5 0 0 0 0	0 0 1 4+0 0.0 0 0	0 0 5 0.0 0 0

*NOTE: D is distance interval for which elevations are desired; e. g. every 10 ft; every 50 ft; etc.

STATIONS: ADD TO OUTPUT ________
SUB. FROM OUTPUT ________
ELEVATIONS: ADD TO OUTPUT ________
SUB. FROM OUTPUT ________

INPUT FORWARDED: DATE: ________
OUTPUT TO BE RETURNED TO: N.Y.
(K.C. or N.Y.)

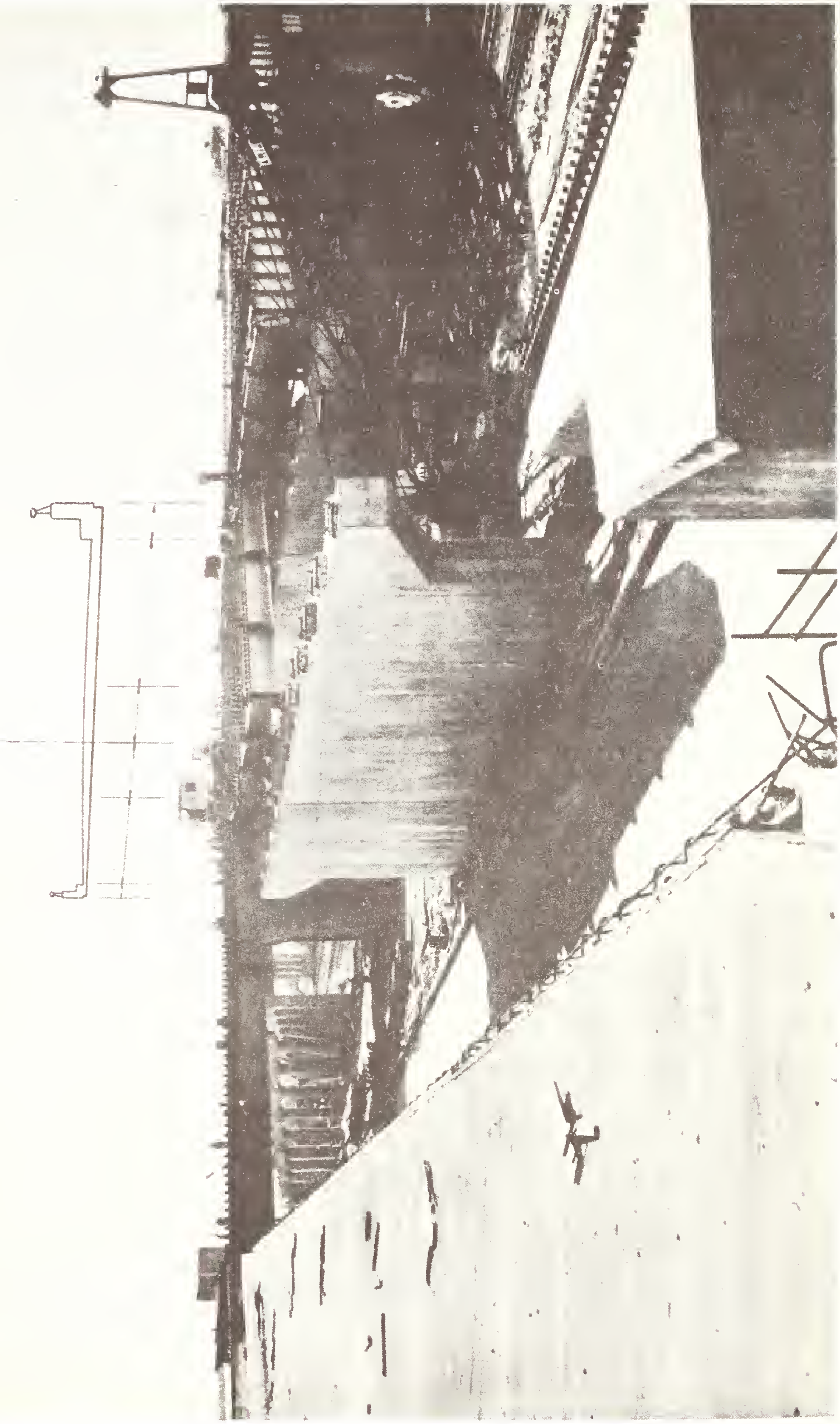
Sheet ____ of ____

INPUT DATA

7 1	4 00.000	357.300	1.950-	5.000	400.000
7 1	4 00.000	357.300	1.950-	5.000	400.000
7 2	10 00.000	387.300	5.000	5.000-	500.000
7 6	1 50.000	1400 00.0			

OUTPUT DATA

	Station of Point	Elevation	Tangent Grade
7 7	1 50.000	362.175	1.950-
7 7	2 00.000	361.200	1.950-
7 7	2 50.000	360.396	1.055-
7 7	3 00.000	360.085	190-
7 7	3 50.000	360.206	675
7 7	4 00.000	360.760	1.540
7 7	4 50.000	361.746	2.405
7 7	5 00.000	363.165	3.270
7 7	5 50.000	365.016	4.135
7 7	6 00.000	367.300	5.000
7 7	6 50.000	369.800	5.000
7 7	7 00.000	372.300	5.000
7 7	7 50.000	374.800	5.000
7 7	8 00.000	377.050	4.000
7 7	8 50.000	378.800	3.000
7 7	9 00.000	380.050	2.000
7 7	9 50.000	380.800	1.000
7 7	10 00.000	381.050	
7 7	10 50.000	380.800	1.000-
7 7	11 00.000	380.050	2.000-
7 7	11 50.000	378.800	3.000-
7 7	12 00.000	377.050	4.000-
7 7	12 50.000	374.800	5.000-
7 7	13 00.000	372.300	5.000-
7 7	13 50.000	369.800	5.000-
7 7	14 00.000	367.300	5.000-



F I G U R E 4

Superimposed on this construction photograph of a pier are typical geometric plan dimensions which must be computed before the design and detailing calculations for superstructure can be started.

The two input forms which are required to allow for triple-compound curvature are reproduced on the next two pages. Note that ten intersecting roadway lines are provided for, and that the number of piers may be increased by using additional second sheets, with any combination allowable up to a maximum of thirty-three intersections per problem.

A portion of the output data follows the input forms.

Coordinates Increase

N [X] E [X]

S [ ] W [ ]
(59) (60)

CHECK TWO BOXES
(NE, NW, SE or SW)

NOTE: Duplicate Columns 1 thru 20 and 59 & 60 on all following cards.

HORIZONTAL ALINEMENT DATA

Card Type 21	Line No. 22-23	Center Coordinates* North 24-32	Center Coordinates* East 33-41	Bearing POC or tangent 42-50 (° ' ")	Radius** 51-58	
1	1	414189727	372166327	N 62 06 20 0 E	00000000	Line #1
2	1					
3	1					
1	2	414237564	372141005	N 62 06 20 0 W	00000000	Line #2
2	2					
3	2					
1	3	414239110	372140186	N 62 06 20 0 E	00000000	Line #3
2	3					
3	3					
1	4	414303849	372105917	N 62 06 20 0 E	00000000	Line #4
2	4					
3	4					
1	5	414305326	372105098	N 62 06 20 0 E	00000000	Line #5
2	5					
3	5					

****Radius**:
for curve right fill in (-)
for curve left fill in (+)
in box.

COORDINATES: ADD TO OUTPUT ________
SUB. FROM OUTPUT ________

INPUT FORWARDED: DATE: ________
OUTPUT TO BE RETURNED TO: ________
K.C. or N.Y.)

Sheet ____ of ____

HORIZONTAL ALINEMENT DATA

Card Type	Line No.	Center Coordinates* North	Center Coordinates* East	Bearing POC or tangent	Radius**	
21	22-23	24-32	33-41	42-50	51-58	Line #6
1	6	414357651	372077437	N 62°06'20.0"E	00000000	
2	6			° ' "		
3	6			° ' "		Line #7
1	7			° ' "		
2	7			° ' "		
3	7			° ' "		Line #8
1	8			° ' "		
2	8			° ' "		
3	8			° ' "		Line #9
1	9			° ' "		
2	9			° ' "		
3	9			° ' "		Line #10
1	10			° ' "		
2	10			° ' "		
3	10			° ' "		

NOTES:
1. For single tangent interval N_o E_o are coordinates of any point on the line; β_{POC} is bearing of tangent. Fill in zeros for "Radius".
2. If line has a tangent interval N_o E_o are coordinates of POC at the right hand side of tangent except if line ends with tangent, then N_o E_o are coordinates of POC at left hand side of tangent. Fill in zeros for "Radius".
3. If single curve interval fill in zeros for β_{POC}.
4. If compound curve interval β_{POC} is bearing at point of tengency.

℄ PIER DATA

Card Type	Pier No.	Ref. Coordinates * North	Ref. Coordinates * East	Bearing of ℄ Pier
21	22-23	24-32	33-41	42-50
4	1	414218.674	372105.435	N 74°23'10.0"W
4	2	414226.619	372107.655	N 74°23'10.0"W
4	3	414234.565	372109.876	N 74°23'10.0"W
4	4	414242.510	372112.096	N 74°23'10.0"W
4	5	414250.456	372114.317	N 74°23'10.0"W
4	6	414299.574	372128.043	N 74°23'10.0"W
4	7	414307.520	372130.264	N 74°23'10.0"W
4	8	414315.465	372132.484	N 74°23'10.0"W
4	9	414323.411	372134.705	N 74°23'10.0"W
4	10	414331.356	372136.925	N 74°23'10.0"W

*Ref. Coordinates are for any one point on ℄ of Pier

INPUT DATA

2	1	1	414189.727	372166.327	N	62	6	20.	E	414189.727	N E
2	2	1	414237.564	372141.005	N	62	6	20.	E	414237.564	N E
2	3	1	414239.110	372140.186	N	62	6	20.	E	414239.110	N E
2	4	1	414303.849	372105.917	N	62	6	20.	E	414303.849	N E
2	5	1	414305.396	372105.098	N	62	6	20.	E	414305.396	N E
2	6	1	414357.651	372077.437	N	62	6	20.	E	414357.651	N E

OUTPUT DATA

			Coordinates of Ref. Pt. or Intersect. North	East	Bearing of Pier	L	d	Coord. Syst.
2	1	4	414218.674	372105.435	N 74 23 10. W			N E
2	1	5	414197.534	372181.076		78.539-		N E
2	1	5	414218.674	372105.435			78.539	N E
2	1	5	414218.695	372105.359		.078	.078	N E
2	1	5	414219.379	372102.912		2.619	2.541	N E
2	1	5	414248.015	372000.442		109.015	106.396	N E
2	1	5	414248.700	371997.993		111.558	2.542	N E
2	1	5	414271.815	371915.283		197.437	85.879	N E
2	2	4	414226.619	372107.655	N 74 23 10. W			N E
2	2	5	414203.140	372191.666		87.230-		N E
2	2	5	414224.300	372115.949		8.612-	78.618	N E
2	2	5	414224.984	372113.502		6.071-	2.541	N E
2	2	5	414226.619	372107.655			6.071	N E
2	2	5	414253.621	372011.032		100.325	100.325	N E
2	2	5	414254.306	372008.583		102.867	2.542	N E
2	2	5	414277.420	371925.873		188.747	85.879	N E
2	3	4	414234.565	372109.876	N 74 23 10. W			N E
2	3	5	414208.747	372202.258		95.922-		N E
2	3	5	414229.907	372126.541		17.303-	78.618	N E
2	3	5	414230.591	372124.093		14.762-	2.541	N E
2	3	5	414234.565	372109.876			14.762	N E
2	3	5	414259.228	372021.623		91.633	91.633	N E
2	3	5	414259.912	372019.175		94.176	2.542	N E
2	3	5	414283.027	371936.464		180.055	85.879	N E
2	4	4	414242.510	372112.096	N 74 23 10. W			N E
2	4	5	414214.353	372212.848		104.612-		N E
2	4	5	414235.513	372137.131		25.994-	78.618	N E
2	4	5	414236.197	372134.683		23.453-	2.541	N E

OUTPUT DATA

			Coordinates of Ref. Pt. or Intersect. North	East	Bearing of Pier	L	d	Coord. Syst.
2	4	5	414242.510	372112.096			23.453	N E
2	4	5	414264.834	372032.213		82.942	82.942	N E
2	4	5	414265.518	372029.765		85.485	2.542	N E
2	4	5	414288.633	371947.054		171.364	85.879	N E
2	5	4	414250.456	372114.317	N 74 23 10. W			N E
2	5	5	414219.959	372223.440		113.304-		N E
2	5	5	414241.120	372147.722		34.685-	78.618	N E
2	5	5	414241.804	372145.275		32.144-	2.541	N E
2	5	5	414250.456	372114.317			32.144	N E
2	5	5	414270.441	372042.805		74.251	74.251	N E
2	5	5	414271.125	372040.356		76.794	2.542	N E
2	5	5	414294.240	371957.646		162.673	85.879	N E
2	6	4	414299.574	372128.043	N 74 23 10. W			N E
2	6	5	414254.616	372288.911		167.032-		N E
2	6	5	414275.777	372213.194		88.413-	78.618	N E
2	6	5	414276.461	372210.746		85.872-	2.541	N E
2	6	5	414299.574	372128.043			85.872	N E
2	6	5	414305.098	372108.276		20.523	20.523	N E
2	6	5	414305.782	372105.827		23.066	2.542	N E
2	6	5	414328.897	372023.117		108.945	85.879	N E
2	7	4	414307.520	372130.264	N 74 23 10. W			N E
2	7	5	414260.223	372299.502		175.723-		N E
2	7	5	414281.383	372223.785		97.105-	78.618	N E
2	7	5	414282.067	372221.338		94.563-	2.541	N E
2	7	5	414307.520	372130.264			94.563	N E
2	7	5	414310.704	372118.868		11.832	11.832	N E
2	7	5	414311.389	372116.419		14.374	2.542	N E
2	7	5	414334.503	372033.709		100.254	85.879	N E

F I G U R E 5

The structures on an interchange such as the Milwaukee Stadium Interchange contain all the complexities of compound horizontal alinement, vertical curvature, and superelevating decks. The calculation of pavement elevations along stringers, above shoes, and at critical points, as well as the determination of depths to flange of steel to determine haunch thickness and geometric camber, is illustrated by the three input forms which follow. A portion of the large quantity of output data is reproduced on the succeeding three pages.

Coordinates Increase

N [x] E [x]

S [ ] W [ ]

(79) (80)

CHECK TWO BOXES (NE, NW, SE or SW)

NOTE: Duplicate Columns 1 thru 20 and 79 & 80 on all following cards.

HORIZONTAL ALINEMENT DATA

Card Type	Segm. No.	Segm. Type*	Coordinates (See Note) North	Coordinates (See Note) East	Station of POC	Bearing POC β_{POC}	Radius **
21	22	23	24-32	33-41	42-50	51-59	60-69
1	1	9	4 1 8 1 3 5 7 6 2	3 6 9 5 1 0 4 0 2	1 5 6 5+4 7 5 4 0	N 7 4° 2 3' 1 0 0" W	0 0 0 3 0 1 5 5 7 0
1	2				+	° ' "	0 0
1	3				+	° ' "	0 0

***Segm. Type**: For tangent fill in 8
For curve fill in 9

****Radius**: For curve right fill in +
For curve left fill in - } in box

Note: 1. If segment is tangent interval, coordinates are for reference point on tangent, Sta. POC is station of reference point, β POC is bearing of tangent and space provided for "Radius" should be filled in with zeros.

2. If segment is curve interval, coordinates are for center of curve, Sta. POC is station of reference point of first compounding and βPOC is tangent bearing at reference point of first compoundir

3. If line is compounded: if there is one Point of Compounding (POC), repeat Sta. POC and Bearing POC on second line; if there are two POC's. repeat Sta. POC and Bearing POC of second Point of Compounding on third line.

MAIN PROFILE GRADE LINE

Card Type	Segm. No.	Segm. Type*	Station PVI	Elevation PVI	G_1 (See note)	G_2 (See note)	LVC	
21	22	23	24-32	33-39	40-44	45-49	50-56	
2	1	8	1 5 7 0+0 0 0 0 0	1 2 7 1 2 0 0	0 0 3 1 5	0 0 0 0 0	0 0 0 0 0 0 0	Segment #1
2	2	9	+					Segment #2

***Segm. Type**: For tangent fill in 8
For curve fill in 9

NOTE: 1. If line is tangent fill in zeros for G_2 and LVC in first line; omit entire second line.

2. For G_1 and G_2 fill in either plus or minus sign in box.

COORDINATES: ADD TO OUTPUT E 2,000,000
SUB. FROM OUTPUT ______
STATIONS: ADD TO OUTPUT ______
SUB. FROM OUTPUT 100,000
ELEVATIONS: ADD TO OUTPUT ______
SUB. FROM OUTPUT 1,000

INPUT FORWARDED: DATE: ______
OUTPUT TO BE RETURNED TO: NY
(K.C. or N.Y.)

Sheet ___ of ___

CROSS SECTION DATA

Card Type	Crown Line At*	PGL At**		L_1	L_2	L_3
21	22	23	24-28	29-33	34-38	39-43
3	2	2	00000	12000	24000	00000
Card Type		Median At***	±D	$\pm S_1$	$\pm S_2$	$\pm S_3$
4	0	8	− 30000	− 02083	− 02083	00000

*Crown Line: ** PGL At: Fill in the number of the point at which both crown line and PGL occur (i.e. 1, 2, 3 or 4)

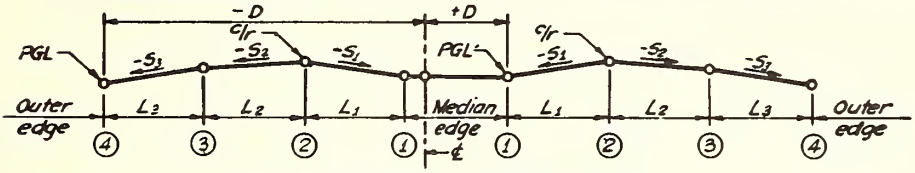
*** Median At: For median at right fill in 8; For median at left fill in 9

NOTE: 1. For D, S1, S2 & S3 fill in plus or minus sign in box. (S will be + only when roadway is dished.)
D = Distance from ℄ to PGL. If: 1) PGL to the right of ℄, fill in (+)
2) PGL to the left of ℄, fill in (-)

2. If L_3 or L_2 and L_3 does not exist, fill in zeros in spaces provided for L_3 or L_2 and L_3 and S_3 or S_2 and S_3.

3. If roadway is on normal section omit filling out transition profile grade information (Cards type 5, 6, 7 or 8) and check this box

Key-punch operator: Duplicate cards 3 & 4 if this box is checked ☐



TYPICAL Normal Cross-Section.

TRANSITION PROFILE GRADES

Card Type	Segm. No.	Segm. Type*	Sta. PVI (See Note)	El. PVI (See Note)	G_1	G_2 or = G_1	LVC or L. T.
21	22	23	24-32	33-39	40-44	45-49	50-56
5	1	9	1564+97540	1272283	− 00315	+ 00685	0100000
5	2	9	1565+97540	1272968	+ 00685	− 00315	0100000
5	3	8	1566+47540	1272810	− 00315	− 00315	1000000
5	4		+				
5	5		+				
5	6		+				
6	1		+				
6	2		+				
6	3		+				
6	4		+				
6	5		+				
6	6		+				

1st transition at outer edge (card type 5)

2nd transition at outer edge (card type 6)

TRANSITION PROFILE GRADES

Card Type	Segm. No.	Segm. Type*	Sta. PVI (See Note)	El. PVI (See Note)	G_1	G_2 or = G_1	LVC or L. T.	
21	22	23	24-32	33-39	40-44	45-49	50-56	1st transition at median
7	1	8	1564+97540	1272533	− 00315	− 00315	1000000	
7	2		+					
7	3		+					
7	4		+					
7	5		+					
7	6		+					2nd transition at median
8	1		+					
8	2		+					
8	3		+					
8	4		+					
8	5		+					
8	6		+					

*Segm. Type: For tangent fill in 8
For curve fill in 9

NOTE:
1. If line is tangent, give station and elevation at the beginning of interval, fill in $G_2 = G_1$ and give LVC as length of tangent.
2. For G_1 and G_2 fill in either plus or minus sign in box.

STRINGER DATA

Card Type	Str. No.	Beginning Coordinates		End Coordinates		Depth to Flange	
		N_1	E_1	N_2	E_2	T_1	T_2
21	22-23	24-32	33-41	42-50	51-59	60-64	65-69
9	1	415254102	368540275	415243429	368572143	00771	00771
9	2	415242811	368574050	415224549	368632369	00771	00771
9	3	415223972	368634286	415214518	368666972	00771	00771
9	4	415248545	368538897	415237873	368570765	00771	00771
9	5	415237255	368572672	415218993	368630991	00771	00771
9	6	415218416	368632908	415208962	368665594	00771	00771
9	7	415242989	368537519	415232317	368569387	00771	00771
9	8	415231699	368571294	415213437	368629613	00771	00771
9	9	415212860	368631530	415203406	368664216	00771	00771
9	10	415237433	368536141	415226761	368568009	00771	00771
9	11	415226143	368569916	415207880	368628235	00771	00771
9	12	415207304	368630152	415197850	368662838	00771	00771
9	13	415231887	368534763	415221205	368566631	00771	00771
9	14	415220587	368568538	415202324	368626857	00771	00771
9	15	415201747	368628774	415192294	368661459	00771	00771
9	16	415226321	368533384	415215648	368565252	00771	00771
9	17	415215030	368567159	415196767	368625478	00771	00771
9	18	415196190	368627395	415186736	368660081	00771	00771
9	19	415220763	368532006	415210091	368563874	00771	00771
9	20	415209473	368565781	415191211	368624100	00771	00771

NOTE:
1. If elevation of points not on a stringer are desired, fill in only spaces for "Beginning Coordinates": one point per card, fill in zeros in remaining columns.
2. T_1 and T_2 is thickness of pavement at each end of stringer.

INPUT DATA

6 1 19	418135.762	369510.402	1565 47.540	N 74 23 10.0 W	3015.570	N E
6 2 18	1570 00.000	1271.200	.315-			N E
6 3 22		12.000	24.000			N E
6 4 08	30.000-	2.083-	2.083-			N E
6 5 19	1564 97.540	1272.283	.315-	.685	100.000	N E
6 5 29	1565 97.540	1272.968	.685	.315-	100.000	N E
6 5 38	1566 47.540	1272.810	.315-	.315-		N E
6 7 18	1564 97.540	1272.533	.315-	.315-		N E

OUTPUT DATA

	Coordinates North	Coordinates East	Station of Point	Pavement Elevation	Slab Thickn.	String. Point	Coord. Syst.
6 9 01	415254.102	368540.275	415243.429	368572.143	.771	.771	N E
6	1415254.102	368540.275	1567 05.024	1272.025	.771		N E
6	1415253.034	368543.461	1567 01.691	1272.035	.770	.100	N E
6	1415251.967	368546.648	1566 98.358	1272.046	.770	.200	N E
6	1415251.433	368548.242	1566 96.691	1272.051	.770	.250	N E
6	1415250.900	368549.835	1566 95.024	1272.056	.770	.300	N E
6	1415249.832	368553.022	1566 91.692	1272.067	.770	.400	N E
6	1415248.765	368556.209	1566 88.358	1272.078	.770	.500	N E
6	1415247.698	368559.395	1566 85.025	1272.089	.770	.600	N E
6	1415246.631	368562.582	1566 81.692	1272.099	.770	.700	N E
6	1415246.097	368564.176	1566 80.026	1272.105	.770	.750	N E
6	1415245.563	368565.769	1566 78.359	1272.110	.770	.800	N E
6	1415244.496	368568.956	1566 75.026	1272.121	.770	.900	N E
6	1415243.429	368572.143	1566 71.693	1272.133	.771	1.000	N E
6 9 02	415242.811	368574.050	415224.549	368632.369	.771	.771	N E
6	2415242.811	368574.050	1566 69.705	1272.139	.771		N E
6	2415240.984	368579.881	1566 63.645	1272.157	.769	.100	N E
6	2415239.158	368585.713	1566 57.584	1272.175	.769	.200	N E
6	2415238.245	368588.629	1566 54.554	1272.184	.768	.250	N E
6	2415237.332	368591.545	1566 51.524	1272.194	.768	.300	N E
6	2415235.506	368597.377	1566 45.463	1272.212	.768	.400	N E
6	2415233.680	368603.209	1566 39.402	1272.231	.767	.500	N E
6	2415231.853	368609.041	1566 33.341	1272.251	.768	.600	N E
6	2415230.027	368614.873	1566 27.280	1272.270	.768	.700	N E
6	2415229.114	368617.789	1566 24.250	1272.280	.768	.750	N E
6	2415228.201	368620.705	1566 21.220	1272.290	.769	.800	N E
6	2415226.375	368626.536	1566 15.159	1272.310	.769	.900	N E
6	2415224.549	368632.369	1566 09.099	1272.330	.771	1.000	N E
6 9 03	415223.972	368634.286	415214.518	368666.972	.771	.771	N E
6	3415223.972	368634.286	1566 07.113	1272.337	.771		N E
6	3415223.026	368637.554	1566 03.739	1272.347	.770	.100	N E
6	3415222.081	368640.823	1566 00.364	1272.357	.770	.200	N E
6	3415221.608	368642.457	1565 98.677	1272.362	.770	.250	N E
6	3415221.135	368644.091	1565 96.990	1272.367	.770	.300	N E
6	3415220.190	368647.360	1565 93.616	1272.377	.770	.400	N E
6	3415219.245	368650.629	1565 90.241	1272.387	.770	.500	N E
6	3415218.299	368653.897	1565 86.867	1272.397	.770	.600	N E
6	3415217.354	368657.166	1565 83.492	1272.408	.770	.700	N E
6	3415216.881	368658.800	1565 81.805	1272.413	.770	.750	N E
6	3415216.408	368660.434	1565 80.118	1272.418	.770	.800	N E
6	3415215.463	368663.703	1565 76.743	1272.429	.770	.900	N E
6	3415214.518	368666.972	1565 73.368	1272.439	.771	1.000	N E
6 9 04	415248.545	368538.897	415237.873	368570.765	.771	.771	N E
6	4415248.545	368538.897	1567 04.562	1272.145	.771		N E
6	4415247.477	368542.083	1567 01.235	1272.155	.770	.100	N E

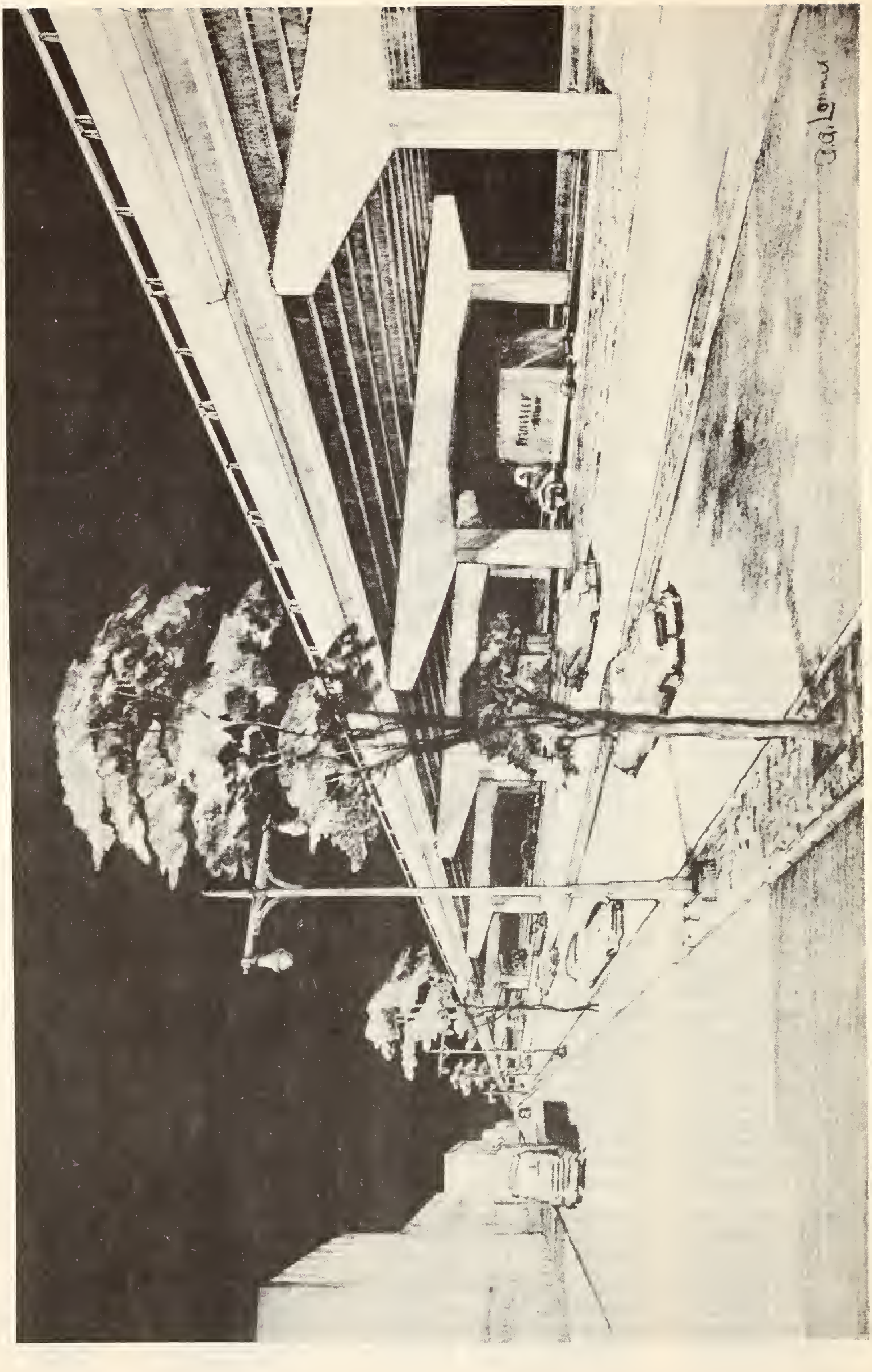
INPUT DATA

OUTPUT DATA

	Coordinates North	Coordinates East	Station of Point	Pavement Elevation	Slab Thickn.	String. Point	Coord. Syst.
6	4415246.410	368545.270	1566 97.908	1272.166	.770	.200	N E
6	4415245.877	368546.864	1566 96.245	1272.171	.770	.250	N E
6	4415245.343	368548.457	1566 94.581	1272.176	.770	.300	N E
6	4415244.276	368551.644	1566 91.254	1272.187	.770	.400	N E
6	4415243.209	368554.831	1566 87.927	1272.198	.770	.500	N E
6	4415242.141	368558.017	1566 84.601	1272.209	.770	.600	N E
6	4415241.074	368561.204	1566 81.274	1272.219	.770	.700	N E
6	4415240.541	368562.798	1566 79.610	1272.225	.770	.750	N E
6	4415240.007	368564.391	1566 77.947	1272.230	.770	.800	N E
6	4415238.940	368567.578	1566 74.620	1272.241	.770	.900	N E
6	4415237.873	368570.765	1566 71.294	1272.253	.771	1.000	N E
6 9 05	415237.255	368572.672	415218.993	368630.991	.771	.771	N E
6	5415237.255	368572.672	1566 69.310	1272.259	.771		N E
6	5415235.428	368578.503	1566 63.261	1272.277	.770	.100	N E
6	5415233.602	368584.335	1566 57.211	1272.295	.769	.200	N E
6	5415232.689	368587.251	1566 54.187	1272.304	.769	.250	N E
6	5415231.776	368590.167	1566 51.162	1272.314	.769	.300	N E
6	5415229.950	368595.999	1566 45.112	1272.332	.769	.400	N E
6	5415228.124	368601.831	1566 39.063	1272.351	.769	.500	N E
6	5415226.297	368607.663	1566 33.013	1272.370	.769	.600	N E
6	5415224.471	368613.495	1566 26.964	1272.389	.769	.700	N E
6	5415223.558	368616.411	1566 23.939	1272.399	.769	.750	N E
6	5415222.645	368619.327	1566 20.915	1272.409	.770	.800	N E
6	5415220.819	368625.158	1566 14.866	1272.428	.770	.900	N E
6	5415218.993	368630.991	1566 08.816	1272.447	.771	1.000	N E
6 9 06	415218.416	368632.908	415208.962	368665.594	.771	.771	N E
6	6415218.416	368632.908	1566 06.835	1272.453	.771		N E
6	6415217.470	368636.176	1566 03.467	1272.463	.770	.100	N E
6	6415216.525	368639.445	1566 00.099	1272.472	.770	.200	N E
6	6415216.052	368641.079	1565 98.415	1272.477	.770	.250	N E
6	6415215.579	368642.713	1565 96.731	1272.482	.770	.300	N E
6	6415214.634	368645.982	1565 93.363	1272.492	.770	.400	N E
6	6415213.689	368649.251	1565 89.994	1272.502	.770	.500	N E
6	6415212.743	368652.519	1565 86.626	1272.511	.770	.600	N E
6	6415211.798	368655.788	1565 83.258	1272.521	.770	.700	N E
6	6415211.325	368657.422	1565 81.574	1272.526	.770	.750	N E
6	6415210.852	368659.056	1565 79.890	1272.531	.770	.800	N E
6	6415209.907	368662.325	1565 76.522	1272.541	.771	.900	N E
6	6415208.962	368665.594	1565 73.153	1272.551	.771	1.000	N E
6 9 07	415242.989	368537.519	415232.317	368569.387	.771	.771	N E
6	7415242.989	368537.519	1567 04.102	1272.265	.771		N E
6	7415241.921	368540.705	1567 00.781	1272.276	.770	.100	N E
6	7415240.854	368543.892	1566 97.460	1272.286	.770	.200	N E
6	7415240.321	368545.486	1566 95.800	1272.292	.770	.250	N E
6	7415239.787	368547.079	1566 94.139	1272.297	.770	.300	N E

OUTPUT DATA

	Coordinates North	Coordinates East	Station of Point	Pavement Elevation	Slab Thickn.	String. Point	Coord. Syst.
6	7415238.720	368550.266	1566 90.819	1272.307	.770	.400	N E
6	7415237.653	368553.453	1566 87.498	1272.318	.770	.500	N E
6	7415236.585	368556.639	1566 84.178	1272.329	.770	.600	N E
6	7415235.518	368559.826	1566 80.857	1272.340	.770	.700	N E
6	7415234.985	368561.420	1566 79.197	1272.345	.770	.750	N E
6	7415234.451	368563.013	1566 77.537	1272.351	.770	.800	N E
6	7415233.384	368566.200	1566 74.216	1272.362	.770	.900	N E
6	7415232.317	368569.387	1566 70.896	1272.373	.771	1.000	N E
6 9 08	415231.699	368571.294	415213.437	368629.613	.771	.771	N E
6	8415231.699	368571.294	1566 68.915	1272.379	.771		N E
6	8415229.872	368577.125	1566 62.877	1272.397	.772	.100	N E
6	8415228.046	368582.957	1566 56.839	1272.415	.773	.200	N E
6	8415227.133	368585.873	1566 53.820	1272.425	.773	.250	N E
6	8415226.220	368588.789	1566 50.802	1272.434	.774	.300	N E
6	8415224.394	368594.621	1566 44.763	1272.452	.776	.400	N E
6	8415222.568	368600.453	1566 38.725	1272.470	.777	.500	N E
6	8415220.741	368606.285	1566 32.687	1272.488	.777	.600	N E
6	8415218.915	368612.117	1566 26.649	1272.504	.777	.700	N E
6	8415218.002	368615.033	1566 23.630	1272.512	.776	.750	N E
6	8415217.089	368617.949	1566 20.611	1272.520	.775	.800	N E
6	8415215.263	368623.780	1566 14.573	1272.535	.773	.900	N E
6	8415213.437	368629.613	1566 08.535	1272.549	.771	1.000	N E
6 9 09	415212.860	368631.530	415203.406	368664.216	.771	.771	N E
6	9415212.860	368631.530	1566 06.557	1272.553	.771		N E
6	9415211.914	368634.798	1566 03.196	1272.559	.772	.100	N E
6	9415210.969	368638.067	1565 99.834	1272.565	.772	.200	N E
6	9415210.496	368639.701	1565 98.153	1272.568	.773	.250	N E
6	9415210.023	368641.335	1565 96.472	1272.571	.773	.300	N E
6	9415209.078	368644.604	1565 93.110	1272.576	.773	.400	N E
6	9415208.133	368647.873	1565 89.749	1272.582	.773	.500	N E
6	9415207.187	368651.141	1565 86.387	1272.587	.773	.600	N E
6	9415206.242	368654.410	1565 83.025	1272.591	.773	.700	N E
6	9415205.769	368656.044	1565 81.344	1272.594	.773	.750	N E
6	9415205.296	368657.678	1565 79.663	1272.596	.772	.800	N E
6	9415204.351	368660.947	1565 76.301	1272.600	.772	.900	N E
6	9415203.406	368664.216	1565 72.939	1272.604	.771	1.000	N E
6 9 10	415237.433	368536.141	415226.761	368568.009	.771	.771	N E
6	10415237.433	368536.141	1567 03.643	1272.386	.771		N E
6	10415236.365	368539.327	1567 00.328	1272.396	.770	.100	N E
6	10415235.298	368542.514	1566 97.014	1272.407	.770	.200	N E
6	10415234.765	368544.108	1566 95.357	1272.412	.770	.250	N E
6	10415234.231	368545.701	1566 93.700	1272.417	.770	.300	N E
6	10415233.164	368548.888	1566 90.385	1272.428	.770	.400	N E
6	10415232.097	368552.075	1566 87.071	1272.438	.770	.500	N E
6	10415231.029	368555.261	1566 83.756	1272.449	.770	.600	N E



F I G U R E 6

The rigid frame concrete bents on the adjacent rendering illustrate one type of bent which may be designed with our framed bent program. The program has been designed to allow for twenty superstructure members on each cap, for a total of nineteen loading conditions, including live load, dead load, wind load, centrifugal force, and temperature rise and fall.

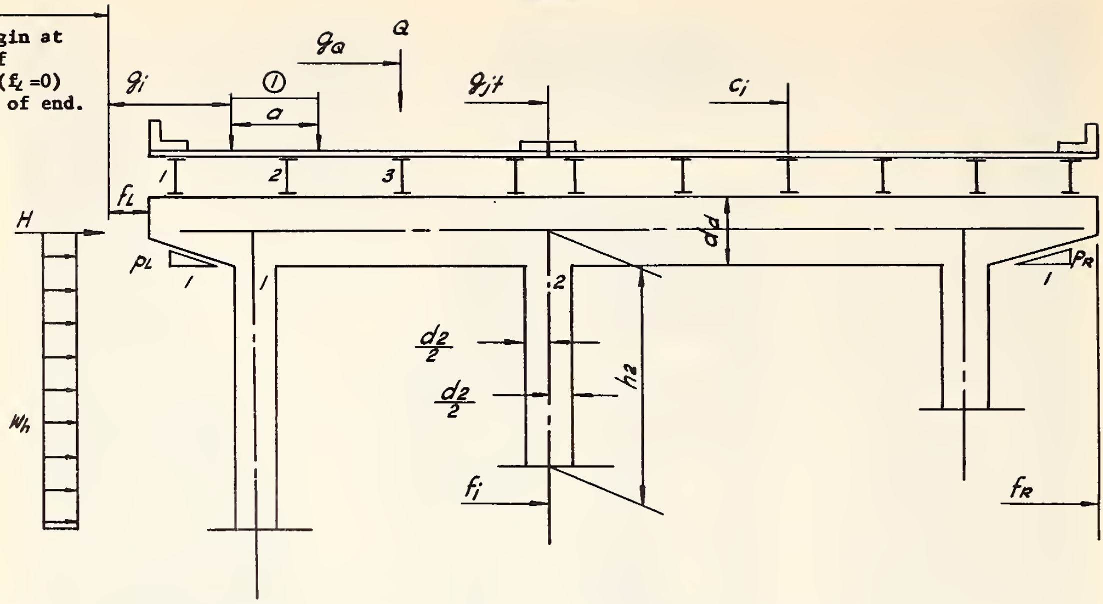
The input forms, reproduced on the next pages (for Phase 1 of the program as described in the text) are lengthy, since, by its nature, the design of a framed bent is not simple.

It will be noted, however, that virtually all the input data shown are necessary geometric dimensions and specified loading conditions, which must be defined before any type of computation can be undertaken.

The output data of this program is very great, containing results for every individual loading condition as well as maximum and minimum moments, shears, and reactions. The number of answers range between 400 and 1000 per problem, and because of this relatively voluminous nature, no attempt has been made to reproduce the output forms.

DIAGRAM

ORIGIN
Select origin at left end of diaphragm ($f_L = 0$) or to left of end.



INPUT DATA

Card No.	Columns		Factor
1	1-5	a	0 6.0 0 0
	6-10	P_{LL}	0 0 4 8.2
	11-15	g_1	0 5.0 0 0
	16-20	g_2	0 8.0 0 0
			$\boxed{-}$
	21-25	g_3	1 8.0 0 0
	26-30	g_4	2 0.0 0 0
	31-35	g_5	3 4.0 0 0
	36-40	g_6	3 6.0 0 0
	41-45	g_7	4 6.0 0 0
	46-50	g_8	4 8.0 0 0
	51-55	g_9	5 8.0 0 0
	56-60	g_{10}	6 0.0 0 0
	61-65	g_{11}	0 0.0 0 0
	66-70	g_{12}	0 0.0 0 0

INPUT DATA

Card No.	Columns		Factor
2	1-5	c_1	0 2.0 0 0
	6-10	c_2	1 0.5 0 0
	11-15	c_3	1 9.0 0 0
	16-20	c_4	2 7.5 0 0
			$\boxed{-}$
	21-25	c_5	3 2.0 0 0
	26-30	c_6	4 0.0 0 0
	31-35	c_7	4 8.0 0 0
	36-40	c_8	5 5.0 0 0
	41-45	c_9	6 2.0 0 0
	46-50	c_{10}	6 9.0 0 0
	51-55	c_{11}	0 0.0 0 0
	56-60	c_{12}	0 0.0 0 0
	61-65	c_{13}	0 0.0 0 0
	66-70	c_{14}	0 0.0 0 0
	71-75	c_{15}	0 0.0 0 0
	76-80	c_{16}	0 0.0 0 0

NOTE:
Forces acting on the bent due to the various loading conditions are indicated by the following superscripts:

- 13 = Dead load of superstructure
- 14 = Wind without live load
- 15 = Wind in conjunction with live load
- 16 = Centrifugal force

INPUT DATA

Card No.	Columns		Factor
3	1-5	c_{17}	0 0.0 0 0
	6-10	c_{18}	0 0 0 0 0
	11-15	c_{19}	0 0 0 0 0
	16-20	c_{20}	0 0 0 0 0
	21-25		0 5 0 0 0 No. of stringer following joint. 0 if no joint
	26-30	a_{jt}	3 0.0 0 0 0 if no joint
	31-40	$P_L \div d_d$	0 0 0 5 0 0 0 0 0 0
	41-50	$P_R \div d_d$	0 0.0 4 0 0 0 0 0 0
4	1-10	Q^{14}	0 1 0 6.4 0 0 0 0 0
	11-20	Q^{15}	0 0 3 2.0 0 0 0 0 0
	21-30	g_Q	1 7.7 5 0 0 0 0 0 0
	31-35		0 2.0 0 0 No. of first stringer resisting Q force
	36-40		0 8.0 0 0 No. of last stringer resisting Q force
	41-50	H^{14}	0 0 7 0.6 0 0 0 0 0
	51-60	H^{15}	0 0 3 1.0 0 0 0 0 0
	61-70	w_h^{14}	.1 4 0 0 0 0 0 0 0
	71-80	w_h^{15}	.0 4 2 0 0 0 0 0 0
5*	1-2	G	0 1
	3-4	H	0 2
	5-6	I	0 3
	7-8	J	0 4
	9-10		0 0
	11-12	K	0 5
	13-14	L	0 6
	15-16	M	0 9
	17-18	N	1 0
	19-20		0 0
	21-30		0 0 0 0 1 0.0 0 0 0 Total no. of stringers
	31-40		0 0 0 0 0 6.0 0 0 0 Total no. of lanes
	41-50		0 0 0 0 0 3.0 0 0 0 Total no. of shafts
	51-60	E	0 4 3 2 0 0 0.0 0 0
	61-70		6 0 0 0 0 0 0 0 0 0
	71-80	H^{16}	0 0 3 6.4 0 0 0 0 0

INPUT DATA

Card No.	Columns	Str. No.	Factor
6#		Str. No.	Loads for condition 14
	1-10	(G)	0 0 3 2.2 0 0 0 0 0
	11-20	(H)	0 0 3 2.2 0 0 0 0 0
	21-30	(I)	0 0 3 2.2 0 0 0 0 0
	31-40	(J)	0 0 3 2.2 0 0 0 0 0
	41-50	(K)	0 0 0 0.0 0 0 0 0 0
	51-60	(L)	0 0 0 0.0 0 0 0 0 0
	61-70	(M)	0 0 0 0.0 0 0 0 0 0
	71-80	(N)	0 0 0 0.0 0 0 0 0 0
7		Str. No.	Loads for condition 15
	1-10	(G)	0 0 1 9.2 0 0 0 0 0
	11-20	(H)	0 0 1 9.2 0 0 0 0 0
	21-30	(I)	0 0 1 9.2 0 0 0 0 0
	31-40	(J)	0 0 1 9.2 0 0 0 0 0
	41-50	(K)	0 0 0 0.0 0 0 0 0 0
	51-60	(L)	0 0 0 0.0 0 0 0 0 0
	61-70	(M)	0 0 0 0.0 0 0 0 0 0
	71-80	(N)	0 0 0 0.0 0 0 0 0 0
8		Str. No.	Loads for condition 16
	1-10	(G)	0 0 2 8.4 0 0 0 0 0
	11-20	(H)	0 0 2 8.4 0 0 0 0 0
	21-30	(I)	0 0 2 8.4 0 0 0 0 0
	31-40	(J)	0 0 2 8.4 0 0 0 0 0
	41-50	(K)	0 0 3 0.2 0 0 0 0 0
	51-60	(L)	0 0 3 0.2 0 0 0 0 0
	61-70	(M)	0 0 3 4.4 0 0 0 0 0
	71-80	(N)	0 0 3 4.4 0 0 0 0 0

*Card No. 5: In the factor columns adjacent to the letters G thru N, list in increasing order the nos. of the stringers for which stringer loads are given in conditions 14, 15, & 16.

#Cards Nos. 6, 7, & 8: In the column labeled "Str. No.", copy from card no. 5 the stringer nos. listed next to the letters G to N.

INPUT DATA

Card No.	Columns	Str. No.	Factor
9		Str. No.	Loads for condition 13
	1-10	1	0150.200000
	11-20	2	0108.600000
	21-30	3	0108.600000
	31-40	4	0112.200000
	41-50	5	0102.200000
	51-60	6	0095.600000
	61-70	7	0093.100000
	71-80	8	0090.300000
10		Str. No.	Loads for condition 13
	1-10	9	0090.300000
	11-20	10	0134.200000
	21-30	11	0000.000000
	31-40	12	0000.000000
	41-50	13	0000.000000
	51-60	14	0000.000000
	61-70	15	0000.000000
	71-80	16	0000.000000
11		Str. No.	Loads for condition 13
	1-10	17	0000.000000
	11-20	18	0000.000000
	21-30	19	0000.000000
	31-40	20	0000.000000
12	1-10	I_d	041.6666667
	11-20	w_d	03.00000000
	21-25	f_L	00.000
	26-30	f_R	71.000
	31-35	f_1	08.000
	36-40	h_1	025.00
	41-45	f_2	30.000
	46-50	h_2	020.00
	51-55	f_3	61.000
	56-60	h_3	015.00
	61-65	f_4	00.000
	66-70	h_4	000.00
	71-75	f_5	00.000
	76-80	h_5	000.00

INPUT DATA

Card No.	Columns		Factor
13	1-10		0.000000000 0 for shafts fixed at btm. 1 for shafts pinned at btm.
	11-20	θ_1	0000000000
	21-30	θ_2	0000000000
	31-40	θ_3	0000000000
	41-50	θ_4	0000000000
	51-60	θ_5	0000000000
	61-70		30.00000000 Temp. rise
	71-80		73.30000000 Temp. drop + shrinkage
14	1-10	h_1	025.0000000
	11-20	h_2	020.0000000
	21-30	h_3	015.0000000
	31-40	h_4	000.0000000
	41-50	h_5	000.0000000
	51-60	I_1	007.8750000
	61-70	I_2	012.5052083
	71-80	I_3	012.5052083
15	1-10	I_4	000.0000000
	11-20	I_5	000.0000000
	21-25	$f_1-\frac{1}{2}d_1$	06.500
	26-30	$f_1+\frac{1}{2}d_1$	09.500
	31-35	$f_2-\frac{1}{2}d_2$	28.250
	36-40	$f_2+\frac{1}{2}d_2$	31.750
	41-45	$f_3-\frac{1}{2}d_3$	59.250
	46-50	$f_3+\frac{1}{2}d_3$	62.750
	51-55	$f_4-\frac{1}{2}d_4$	00.000
	56-60	$f_4+\frac{1}{2}d_4$	00.000
	61-65	$f_5-\frac{1}{2}d_5$	00.000
	66-70	$f_5+\frac{1}{2}d_5$	00.000

L. R. Schureman
Bureau of Public Roads

ELECTRONIC COMPUTERS IN CONTINUOUS BEAM BRIDGE DESIGN

In the Bureau of Public Roads, we began working on the application of the electronic computer to bridge design problems about a year and a half ago. Our principal effort has been concentrated on continuous beam bridges--first to determine the extent to which the use of the electronic computer is feasible in their design; and second, to develop a usable program or programs.

Our preliminary investigations extended over a number of weeks. As a result of these investigations, three principal conclusions were reached:

(1) That it would be possible to develop a program in which the computer is given the number of spans,the span lengths and the loads and produces in a continuous computer operation the sizes of the interior and exterior beams required.

(2) That while it would be possible in this kind of computation to develop a single computer program usable for both steel beam and reinforced concrete beam continuous bridges, it would be preferable to use separate programs.

(3) That it would be both possible and desirable to develop a single computer program which could be used for 3-, 4-, and 5-span bridges with either equal or unequal spans.

Based upon these findings, we have developed an electronic computer program for the design of continuous steel beam bridges of 3, 4 or 5 equal or unequal spans. The American Association of State Highway Officials "Standard Specifications for Highway Bridges" are used and the program provides for both H and HS loadings of any class.

The input includes the number of spans, the span lengths and the loads. The output includes the sizes of the interior and exterior beams and the sizes and lengths of flange plates over the piers.

The program is not developed for any particular make of computer. It is expressed in word form and can readily be coded for any computer. It has been coded in part for the ElectroData, Datatron and also for the North American Aviation Recomp II.

The moment distribution method is used because it is well adapted to computer operation and because State highway department designers are thoroughly familiar with it.

The program is divided into seven principal parts:

(A) The computation of the maximum positive moment in each span and the maximum negative moment at each pier for an interior beam using a constant moment of inertia, and from these the tentative design positive moment and the tentative design negative moment.

(B) The determination of the size of the beam needed for the tentative design positive moment and the computation of the number, sizes and lengths of flange plates required for the additional moments at the piers.

(C) The recomputation of design constants (stiffness factors and carry-over factors) taking into account the variation in moment of inertia due to the flange plates.

(D) A repetition of Part A to determine new design moments.

(E) A repetition of Part B to redetermine required beam and flange plate sizes.

(F) Checks for shear and deflection.

(G) A repetition of the entire process to determine beam and flange plate sizes for the exterior beam.

The solution is developed in a form which I believe requires a minimum of computation. First, the stiffness factors, distribution factors and carry-over factors are computed and stored in the computer's "memory." Fixed-end moments are then computed for a unit uniform load on each span. A complete moment distribution computation is then made for unit uniform load in the first span only and the resulting moments at the supports are stored. This part of the program is then repeated successively for unit uniform load in the other spans with only one span loaded in each case. For each repetition, the resulting moments at the supports are stored for later use.

These moments at the supports are then combined to provide the basic data needed to compute moments at the supports for actual uniform live load on any combination of spans and for actual dead load on all spans. Positive moments for uniform live load and dead load are obtained by applying the laws of statics.

Fixed-end moments are then computed for a unit concentrated load placed in each span successively to produce maximum positive moments. The ratios of these fixed-end moments to corresponding fixed-end moments for unit uniform load are then applied to the effects of the unit uniform load condition to determine the moments at the supports for each unit concentrated load condition. Positive moments are again determined from the laws of statics.

In this way, the step-by-step moment distribution process is programed only once. This sequence of instructions is used first for unit uniform load in span 1. It is then repeated for unit uniform load in the other spans by using a cycling or looping procedure. For unit concentrated live load and wheel loads, the moments at the supports are computed from ratios of fixed-end moments, thus eliminating the moment distribution routine entirely for such loads. These devices shorten the program appreciably.

The moments produced by the unit loads are then multiplied by the given values of dead load, uniform live load and concentrated live load, with the specified allowance for impact, to obtain maximum positive moments for lane loading and maximum negative moments for lane loading. These values are stored as they are computed.

The maximum positive and maximum negative moments for H truck and HS truck loadings are obtained and stored in the same way using in each case the fixed-end moments corresponding to the load condition involved.

The maximum moments for lane loading are then compared with the maximum moments for H truck loading and the larger values stored and printed as the design positive moment and the design negative moment for H loading. If HS loading is specified, the H truck loading computations are bypassed and the design positive and negative moments are determined by comparing maximum moments for lane loading with maximum moments for HS truck loading. Similarly if H loading is specified, the HS truck loading computations are bypassed.

The size of the beam required for the design positive moment is then determined. For this purpose, a table of wide flange beam sizes arranged in the order of their section moduli and covering an appropriate range is stored in the computer's memory. The section modulus required for the design positive moment is computed and using this value, the computer selects the appropriate beam from the stored table. If the required section modulus is larger than any value in the stored table, the computer prints its value and stops.

The section modulus required for the design negative moment is then computed and the section modulus of the selected beam is subtracted from it. This is the section modulus which must be furnished by flange plates over the piers.

The procedure for computing flange plate sizes is based on the use of welded flange plates. The width and thickness of the flange of the selected beam provide the limiting values for the widths and thicknesses of the flange plates. Within these limitations, the number of plates required and their widths and thicknesses are determined from the previously computed section modulus to be furnished by the flange plates.

An approximation is used in determining flange plate lengths. The negative moments at points two-tenths of a span length either side of each intermediate support are first computed. Then in each case a straight line variation between this moment and the maximum negative moment at the support is used to determine the end of the flange plate. The partial lengths are added to obtain the total length of the flange plate or plates at each support. This is checked against the minimum length limitation prescribed in the specifications.

In the next part of the program, each span is divided into ten equal segments and the average moment of inertia of each segment is computed. These are used to determine new values for the stiffness and carry-over factors and for fixed-end moments for unit loads. Using these new values, the program is repeated and a second determination of beam and flange plate sizes is made. This usually is sufficient, if not, another cycle can be used.

Checks for deflection and shear are then made and the computation is finished.

As I said in the beginning, one of our objectives in this investigation was to determine if a program could be developed for the entire continuous beam computation. We found that it could--we have the program in the Bureau's library and it is available to anyone who wants it.

In developing the program, we have learned much about the electronic computer--both its capabilities and its limitations. Perhaps the most important thing we have learned is that there should be a realistic division of work between the computer and the designer.

Certainly the designer should not be burdened with tedious, time-consuming arithmetic and this the computer can do very well. On the other hand, we cannot expect a computer to perform the duties of an experienced designer, even with a most carefully prepared program.

For example, in this program, the computer selects a beam large enough to carry the maximum positive moment and then determines the number and sizes of flange plates necessary to carry the additional moment over the piers.

In some cases, it might be preferable to use a smaller beam reinforced with a flange plate within the span to carry the maximum positive moment and with other flange plates over the piers. In other cases, it might be preferable to use a beam large enough for the maximum negative moment and not use any flange plates at all.

These are determinations which should be made by the designer based on his best judgment.

The electronic computer properly used is a very valuable aid to the designer but that is all it is. We must keep in mind that it is simply a computing device. It cannot accumulate experience and it cannot exercise judgment.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Discussion on

The Use of Electronic Computation in Traffic Studies, Traffic Simulation, and Research Analyses

Moderator

John A. Volpe--John A. Volpe Construction Company

Peter J. Caswell--Chicago Area Transportation Study

G. E. Brokke--U. S. Bureau of Public Roads

Gordon D. Gronberg--U. S. Bureau of Public Roads

Paul E. Irick--AASHO Road Test

Conference on Increasing Highway Engineering Productivity
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John A. Volpe
John A. Volpe Construction Company

Gentlemen - the subject for this discussion is "The Use of Electronic Computation in Traffic Studies, Traffic Simulation, and Research Analysis." It is the third of the general fields of highway engineering under which the use of electronic computation is being discussed here. I, however, must take exception to the scheduling of this as the third subject. It is not the third but the first operation to be performed in the building of an adequate highway system, particularly those portions of the system that are in or adjacent to the large urban areas. Also, to my mind, it is the first and not the third in importance.

Included under the general term of traffic studies is a broad field. Such items as the analysis of origin and destination survey data to determine the most logical route insofar as the desire of the traveler to go from one place to another is concerned and traffic assignment to determine the volume of traffic that will use a proposed facility are most important and, if they are to be of value, must be performed well in advance of actual design and construction.

To provide the basic traffic demand information on which the Interstate System is to be designed is a large task. It is a task that would require, using the methods available to us in past years, more engineers that we have available and more time than we have available. The only answer, therefore, is to change the methods, and electronic computation is one of the new methods we can use.

The electronic computer provides a means of analyzing in a very short time the great masses of data that are a part of such studies. The electronic computer not only enables us to obtain the information previously obtained in a much shorter time but it also makes it possible to more thoroughly analyze the data and to obtain from it far greater amounts of pertinent information, We can, therefore, do the work not only quicker but also better.

The analysis of information is not, however, the whole task. We still must obtain the information and translate it into a form in which the electronic computer can use it. These methods are also antiquated and development work leading toward the obtaining of this information in a form that does not require further translation into computer input is desirable.

The advent of the use of the electronic computer in this field brings up another problem. The great effort required to write an adequate computer program makes it necessary that the methods and procedures for this work be standardized to a greater degree.

To date, several States including Illinois, California and Washington and some of the consultants and service organizations have programed the determination of desire lines. We will hear from Mr. Caswell who is with the Chicago Area Transportation Study. California, Illinois and possibly others have programed the assignment of traffic to particular routes. The Bureau of Public Roads, which is represented here today, has developed a program for the determination of traffic growth and distribution by several methods. In addition, they developed a program for the depreciation analysis of the highway plant. This also will be described. The California Institute of Traffic and Transportation Engineering has performed valuable work in the field of traffic simulation on the electronic computer.

Another and most important phase of highway engineering is research analyses. This is the field that provides the basic information in which all other highway engineering depends. Too often, however, the mass of data collected in a research project is so great that ordinary methods of analysis fail to bring out the significant facts. Here again, the electronic computer can be of assistance to us. It can sort out these facts and find the ones that are significant. This not only provides us with the answers that are buried deeply in the masses of data but also shows which of our tests have little or no significance and allows us to eliminate those of little value and concentrate on the more significant phases of the work. And possibly more important, this information will be available almost as soon as the tests are completed, not a year or so later.

With that short introduction of the subject I shall call on the first of our four discussion leaders. Mr. Peter Caswell of the Chicago Area Transportation Study who will discuss the work he and his coworkers have accomplished in adapting electronic computation to their work.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Peter J. Caswell, Assistant Director
Chicago Area Transportation Study

UTILIZATION OF ELECTRONIC COMPUTATION IN TRAFFIC STUDIES, SIMULATION AND RESEARCH ANALYSIS

In development of an overall transportation plan for the greater metropolitan area of Chicago, complete knowledge of all basic forces underlying transportation requirements is necessary. The Chicago Area Transportation Study (CATS) is presently undertaking the collection of basic information to accurately describe these forces and is actively utilizing electronic computing devices.

OVERALL PLANNING PROCESS

The following is a description of the planning process as illustrated in Block Diagram No. 1. This consists of three parts: (1) data collection for three major and three minor inventories; (2) development and testing a method of predicting traffic from land use and transportation facility data; (3) the preparation and testing of transportation plans.

1. The major inventories are of travel, land use and transportation systems and capacities. The minor inventories are population, economics, and public finance and administration.

   a. The Inventory of Trips.

      The inventory of trips is a listing of all trips made by persons or vehicles which have been selected in the sampling process, together with complete information about each trip. In the main, these are standard origin-destination data as approved by the U. S. Bureau of Public Roads. These include the home interview survey - 58,000 dwelling units, 235,000 trips; the truck and taxi survey - 60,000 trips; an external cordon line survey - 65,000 trips; and screen line survey - 100,000 trips.

   b. The Inventory of Land Use and Establishments.

      The second major inventory is the land use and establishment survey, this includes acreage of land use by 12 categories for one-quarter mile sections and a measure of square feet of floor area by 88 categories for each block in 300 square miles of the area - 170,000 records.

   c. The Inventory of Existing Transportation Facilities.

      The third inventory of existing transportation facilities includes measurements of fixed physical

features, features of intersection design and of traffic usage of all major arterial streets in the system. The inventory also includes a location classification and name of each street. A complete inventory is also taken of all mass transportation facilities - 10,000 records.

d. Inventories of Population, Economic Activities and Government Finances and Administration.

1. The three minor inventories of population, economic activities, and government finances and administration are obtained from census material and similar statistical sources. Primarily, these inventories serve as sources for forecasting the future growth and development of the metropolitan area.

2. The key role of testing the data collected in the surveys is in developing the laws of behavior that control trip generation, interchange between zones, and the flows upon the transportation network.

Trip generation from specific zones is readily obtainable from summarization of O-D survey data for the year the survey is taken. Prior studies have indicated that land use properly stratified may yield per acre, or per square foot, a constant rate of trips. Relationships therefore can be established between the land use and the O-D surveys by matching them by predetermined categories for each zone. The resultant ratios, i. e., six trips per residential unit per day, or ten trips per thousand square feet of commercial floor area per day, are applied to the forecast of land use for a future period to obtain trip generation.

The interchange of future trips is simulated by the use of formulas developed by the detailed examination of the present behavior of friction parameters of the area. Consideration of distance, time, and cost as measures of travel friction is undertaken in the development of a mathematical technique to obtain the interchange.

The assignment of trips to the transportation network in the present and future is possible only by study of the behavior of the people as a whole and determining the basic laws governing person movement. Essentially the distribution on a network is based on a cost function and the carrying ability of the available route sections. The cost function developed includes distance, time, parking fee, transfer delays, and other measures. Trips are thus distributed from zones to zones on the network is such that no individual benefits greater than another.

3. Development of a transportation plan includes the use of trip desire lines to a greater degree than previously used. Prior use has included the crude device of manual posting on maps with width as the accumulation medium and the summarization of a large amount of punched cards, each a count of the trips passing through a grid section. The time consumed has dulled the effectiveness of this particular tool. With an analogue computer the time has been reduced to the point where a map of the entire area by any selected group of parameters can be produced in one day. The use of these desire line maps with trip assignment serves as a positive link in the determination of the final transportation plans.

AVAILABLE COMPUTING DEVICES

The use of the electronic computing devices became an extreme necessity when the problem of mass data processing was considered, together with mathematical and statistical procedures necessary to forecast the future generation of trips and assignment. In April 1957, CATS installed a Datatron Electronic Digital Computer. This computer consists of 4,080 words of magnetic drum storage and five magnetic tape units. Each tape is block addressed prior to operation and contains 20,000 blocks of 20 words each. A hundred digit record is stored 40,000 times on one reel of tape. The input to the Datatron computer is an IBM card reader, and the output is an IBM accounting machine. The installation is staffed by an EDPM Supervisor, 5 Programers, and one Computer Operator.

An analogue computing device will be installed during the month of September 1957. This device made to order has been christened the 'Cartotron' and will function as a point or line generation display apparatus. By utilizing the O-D X, Y coordinates, the digital computer is programed to prepare a magnetic tape containing the records to be displayed on the 'Cartotron'. This device will portray a dot or line upon a grid corresponding to the grid upon the area. By means of a camera with a fixed, open shutter, these displays are collected upon a photographic plate. The plates are then processed in photo lab. The resultant grids with dot or line densities accumulated by any one or combination of twenty-two predetermined parameters is forwarded to the Graphics and Design department as a final map.

A problem can be stated as follows: Given a set of all trip records; select a sub-set of records on the basis of trip or land use characteristics, i.e., direction, reason for travel, distance, time of origin, etc., and determine the density of trip desire lines corresponding to the selected sub-set in geographical units. These trip desire line intersections, per quarter square mile, are weighted by an appropriate expansion factor so that the result is representative of the entire population of trips.

A preparation of a trip desire line map using accounting machines with punched cards would take two months and by calculation upon a magnetic drum computer two weeks, prior to delivery to the drafting department for the preparation of a map. The 'Cartotron' will complete a finished map in one day.

Another analogue computing device in use by the Study consists of a resistance network portraying the streets and zonal inputs for a 12 square mile area. This device is used by manipulation of the resistances of the streets to determine the combinations necessary to portray the actual ground conditions.

The use of this small model will possibly furnish clues as to measures of route frictions, adaptability of electronic analogues to the larger network and a study of the equilibrium described by laws of behavior governing person movement.

Another model has been constructed utilizing glow lamps. This expressly portrays the minimum path through a network instantaneously. By further utilization of current storage, feedback can be simulated. This model is effective in further exploration of electronic analogue adaptability, and incidentally is a good demonstration tool.

ELECTRONIC DIGITAL COMPUTER APPLICATION

The applications processed on the Datatron computer primarily concern the actual transfer of information from punched cards to magnetic tape, corresponding accounting checks and the calculation of the dwelling unit and trip factors. The actual production jobs are:

HOME INTERVIEWS

1. HOME INTERVIEW CARD TO TAPE
2. HOME INTERVIEW TAPE ACCOUNTING
3. HOME INTERVIEW PRELIMINARY FACTOR CALCULATIONS
4. HOME INTERVIEW PRELIMINARY FACTOR APPLICATION
5. HOME INTERVIEW SCREENLINE TRIP SUMMARY
6. POPULATION SUMMARIES BY SQUARE MILE-CENSUS TRACT-POLITICAL UNIT
7. TRIP PURPOSE - TO-FROM MATRIX

SCREENLINE

1. SCREENLINE CARD TO TAPE
2. SCREENLINE FACTOR CALCULATIONS
3. APPLY FACTORS TO SCREENLINE TAPE
4. SUMMARY OF SCREENLINE BY T.P. HOUR
5. SCREENLINE INTERVIEWS WITH O AND/OR D OUTSIDE
6. GROUND COUNTS - CARD TO TAPE

TRUCK AND TAXI

1. TRUCK AND TAXI CARD TO TAPE
2. TRUCK AND TAXI PRELIMINARY FACTOR CALCULATIONS
3. TRUCK AND TAXI FACTOR APPLICATION

CORDON LINE

1. LOAD CORDON LINE R. I. CARD TO TAPE
2. CORDON LINE PRELIMINARY FACTOR
3. CORDON LINE FACTOR APPLICATION
4. GROUND COUNTS - CARD TO TAPE

Scientific applications processed include gross and multiple correlation of route section and intersection data, and of speed-volume data. The results of these will be published as soon as analysis is complete. Geometric Mean, Log, Square Root and Matrix Multiplication have been used quite frequently. Future runs will include the inversion of a fifty by fifty matrix, and multiple correlation of many types of problems. The digital computer is very adept at this type of work. The complete gross and multiple correlation of 16 variables with 1,000 cases is completed in less than one hour. Manual solution of the same problem would never be undertaken for economic reasons. This allows the engineer to test hypotheses of cause and effect that otherwise could never be attempted.

Other applications are the preparation of a tape for loading on the 'Cartotron', the basic summary tables requested by the Bureau of Public Roads, and statistical tables necessary for analysis by the Study staff. Future applications will be concerned mainly with forecasting of land use and trip generation for 1965, 1975, and 1985; also complete economic population and financial models for today, 1965, 1975, and 1985.

The interchange and assignment problems are presently being studied in the light of processing by the digital electronic equipment. One method of assignment under discussion was presented by Armour Research Foundation. Armour is under contract to determine applicability of solution of the assignment problem by machine methods. This particular method, a refinement of an algorithm by E. F. Moore, effectively determines the shortest path from any intersection to all other intersections in a manageable amount of time. Each route section could be fixed with a specified amount of carrying ability and the program, adaptable to any computer, would load trips on to the network on the minimum path between zones. By loading a portion of the zonal interchanges, up-dating the route sections and then loading the remainder, this method looks very promising. With our network of 4,000 route sections and intersections and 100,000 zonal interchanges it is estimated the entire assignment could be completed in approximately 30 hours on the largest computer.

Many of these future jobs have already been block diagramed and descriptions written. These block diagrams and accompanying descriptions are forwarded to the program supervisor, who promptly assigns them to program writers for programing, debugging, and computer operation. Block diagraming has been an extremely useful tool in our organization and does present a complete picture, not only to the programing group but also to management. It effectively displays the problem in its entirety and enough detail to eliminate changes at the last minute. This is essentially important, as once a program has been started it is virtually impossible to insert changes without creating significant time loss.

Operation of the electronic digital computer has presented many serious problems. The initial cost of gaining experience both by our staff, and the computer engineer, has been quite high. If one can profit by experience, future users are urged to develop block diagraming and final detail preparation to a fine art. Last minute changes and inadequate detail are definite hazards. Personnel should definitely include one experienced man and others with punched card experience or at least with equivalent accounting logic. One digit missing or incorrect in a program of ten thousand (one thousand steps) renders the entire program worthless.

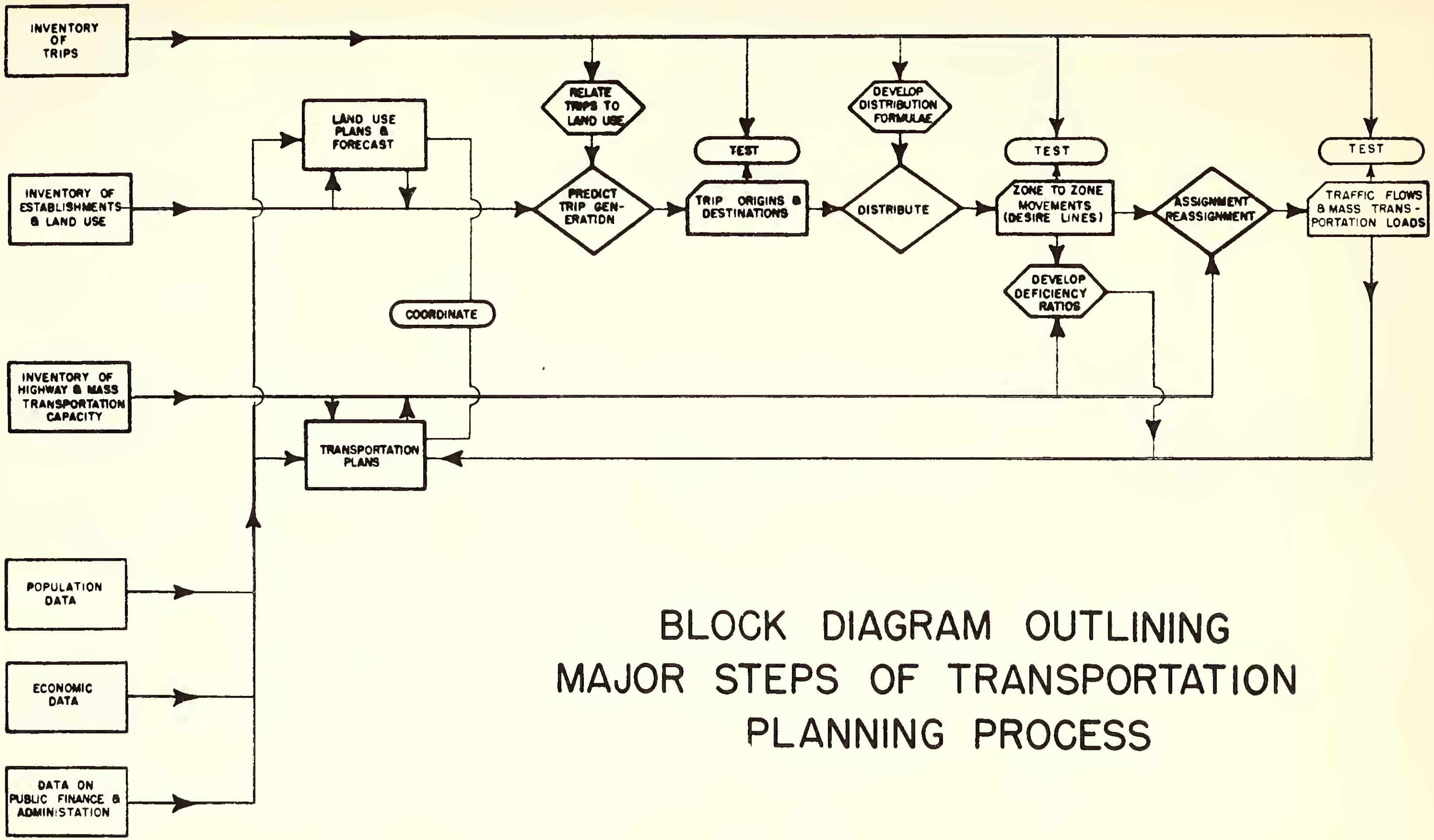
ELECTRONIC ANALOGUE COMPUTER APPLICATIONS

The 'Cartotron' is an electronic analogue device which by geographical orientation can display a dot or line of required density on the face of cathode ray tube. This information is then collected on a photographic negative by means of an open shutter. This negative when developed will accurately portray a density function over the entire area of trip desire, population, economic or land use characteristics.

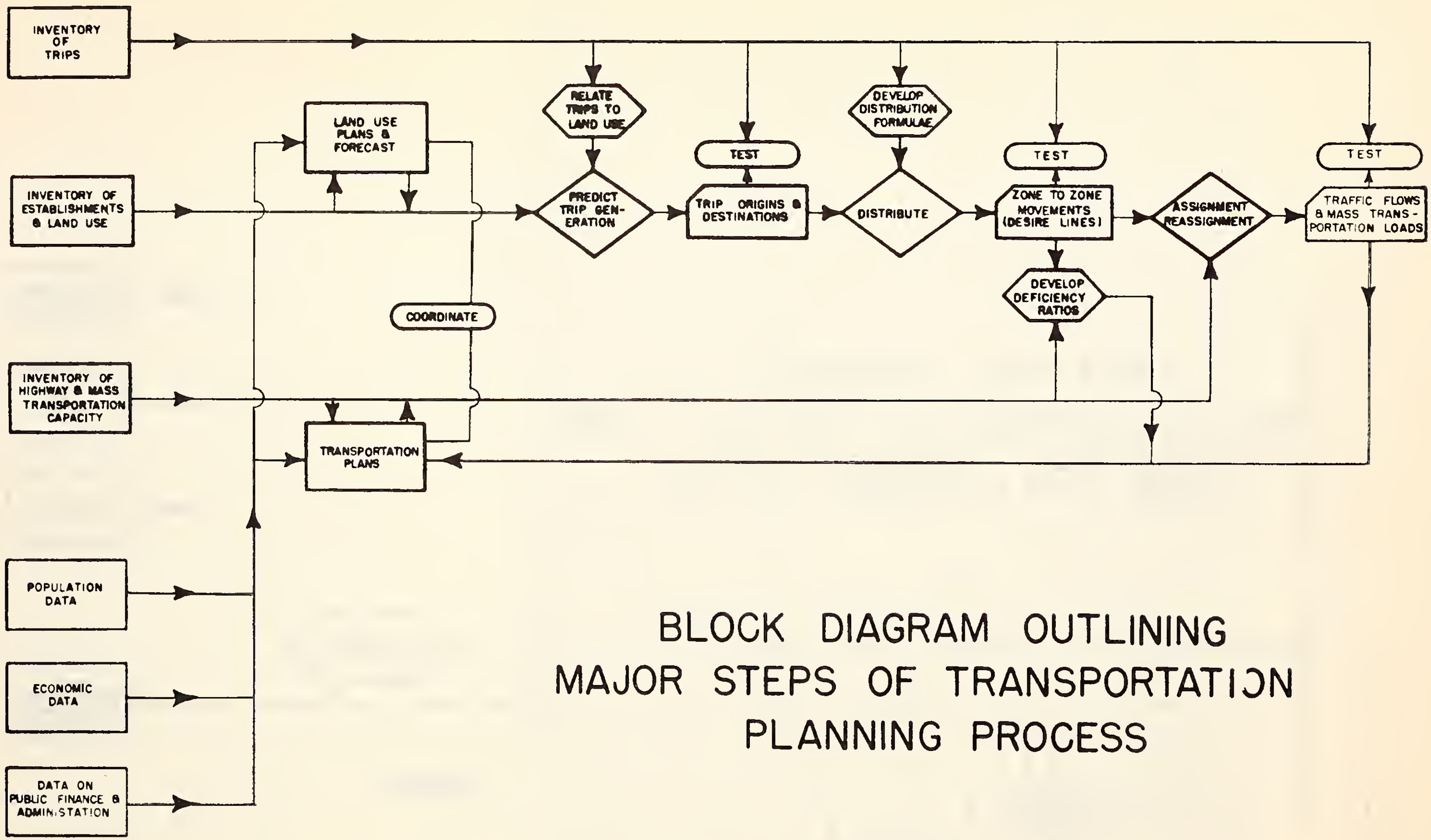
By securing a set of prints enlarged from the negatives, the present grid for the area is overlaid; and the results are desire line maps. This device will then accurately portray to plus or minus, 2%, desire line and density maps by any classification or sub-classification desired, in a matter of 5 to $5\frac{1}{2}$ hours processing time. This will not only supply basic trip desire lines of internal, external, and screen line trips by four major directions but also an extremely selective group of maps. For instance, a map can be portrayed showing all trips lying between zero and $11\frac{1}{4}$ degrees of taxi trips between the hours of 9:00 a.m. and 1:00 p.m.; or a density map can be prepared, portraying all retail establishments of more than 5,000 square feet in first floor area. In each case the sub-unit is $\frac{1}{4}$ square mile. This device is also used for plotting scatter grams prior to correlation, portraying route loading on major streets and preparing traffic capacity maps.

TRANSPORTATION FLOW ANALOGUE COMPUTER

The CATS organization is presently studying the possibility of the design, construction and cost of a specific analogue computer which will accurately portray the transportation system in the Chicago area. This device will be a direct analogy of the transportation system as it exists today or would exist in the future. Each street intersection, railroad, mass transit route, is represented in a device as an electronic pluggable unit. Such a device will accurately portray a transportation flow through the entire system over a twenty-four hour period in less than ten minutes. This would be extremely desirable as particular intersections can be studied in detail and by making adjustments to the streets entering an intersection or the intersection itself, the actual redistribution of traffic could be studied prior to any actual construction. It would, therefore, be possible to try five or six alternate systems, and in less than two hours have the final results of each alternate. This would be extremely useful in determining the applicability of a one-way street, staging expressway construction, relocation of mass transit stations, addition of parking lot in a certain area, closing off a major artery for construction purposes, etc. In each of these cases the resultant configurations could be analyzed to determine the best alternative. The premise of this analogue device is that even though an individual has perfect freedom in choosing his course from an origin to a destination, the transportation flow, as a whole, reaches an equilibrium. It, therefore, portrays the entire transportation flow, and by utilizing electronic components directly proportional to the carrying ability of a particular route section and representing the actual restrictions of each intersection and route section, electronic current through geographical zone-to-zone centers accurately portrays ground conditions.



BLOCK DIAGRAM OUTLINING MAJOR STEPS OF TRANSPORTATION PLANNING PROCESS



BLOCK DIAGRAM OUTLINING
MAJOR STEPS OF TRANSPORTATION
PLANNING PROCESS

Conference on Increasing Highway Engineering Productivity
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G. E. Brokke and W. L. Mertz
Bureau of Public Roads

EVALUATING TRIP FORECASTING METHODS WITH AN ELECTRONIC COMPUTER BY HIGHWAY TRANSPORT RESEARCH DIVISION

Presented by G. E. Brokke

In forecasting future trip distribution from the existing pattern, the average factor method, the Detroit method, and the Fratar method are eqaully accurate if each method is carried through a sufficient number of successive iterations. In all cases tested, the second approximation of the Fratar method was of maximum accuracy while four or more approximations were usually required with the other two methods.

The results of the test emphasized the fact that the majority of the trips within a metropolitan area consist of a very large number of small-volume zone-to-zone movements, where the zones are of normal size. With sampling rates used these individual small-volume movements are not accurately determined. The accumulation of the small-volume movements into volumes associated with ramps, streets, and expressways, should result in acceptable accuracy as calculated by statistical formulae, but this will have to be definitely established by additional research.

The advantage of using an electronic computer on research projects of this type can hardly be overestimated, notwithstanding the difficulty and time consumed in preparing the program. In this series of tests, the speed and accuracy of the computer permitted the attainment of results in hours instead of years after the program had been completed, without a single error attributable to the computer.

Introduction

Home-interview origin and destination studies were made in the Washington, D. C., area in 1948 and in 1955. In the earlier study a 5-percent sample was obtained by interviewing the residents of one of every 20 dwelling units. In the 1955 study, the sample rate was 1 in 30 in the District of Columbia and 1 in 10 elsewhere within the area.

These two surveys offered, for the first time an opportunity to study the changes occurring over a period of several years in a metropolitan area in the pattern of trips, i. e., the differences in the number of trips between the same origins and destinations. They also provided data that could be used to evaluate methods of forecasting future trip volumes.

Trip Forecasting Elements

Two basic elements are involved in the forecasting of trips. One is the increase in the number of trip origins and destinations in a particular part of the city such as a zone. For brevity the number of trip origins and destinations combined have been labeled trip ends. Thus, for example, 2 trips originating in a zone and 3 trips destined to it would be counted as 5 trip ends. Manifestly, if only the trips made wholly within an area are considered, the total number of trip ends in the area is exactly twice the number of trips.

The ratio of the future trip ends expected in a particular zone to the present trip ends in the zone is called the growth factor for that zone. Much work has been and is being done in this field to determine the best method of arriving at the proper growth factor. Up to now, however, forecasts, so far as total trip ends are concerned, are dependent to some extent on personal judgment. In order to eliminate this variable, and isolate the elements being studied, the growth factors were calculated for each zone by taking the ratio of the reported trip ends in each zone in 1955 to the reported trip ends in each zone in 1948. Thus any variability in predicting growth factors will not affect this study of forecasting methods.

The other basic element involved in forecasting zone-to-zone movements is the application of the growth factors of the two terminal zones in predicting the number of future trips between them. Various mathematical formulae have been developed with that end in view. It is the purpose of this study to evaluate the accuracy of these methods and the formulae used therein. Certain other methods of trip forecasting, based on population distribution, trip-attraction distribution, and distance or travel time, directly predict the number of zone-to-zone trips, but as these methods are still in the process of development they will not be further discussed herein.

Characteristics of the Area

One problem that had to be resolved in beginning the test was that the area covered in the 1948 Washington survey was somewhat smaller than that of the 1955 survey, and the extent and identifying numbers of many of the zones had been changed. The first step was to reconcile these differences by rezoning the metropolitan area into 254 zones and to determine both the 1948 and 1955 volumes of trips into and out of these zones.

The 254 zones covered an area which contained 96 percent of the population that lived within the 1948 cordon and 93 percent of that living within the 1955 cordon.

Most of the external cordon stations in 1955 were placed at different locations from those in 1948, and therefore the trips crossing the cordon, called "external" trips, are omitted from the study, the two surveys not being comparable as regards this class of trip.

Within the 254 zones the population increased 38 percent during the 7-year interval while the number of trips by persons 1/ increased 42 percent. This represents a small increase in trips per person from 1.95 to 2.00. During the same interval the number of passenger cars owned by residents almost doubled, increasing 96 percent, while the number of trips made by these passenger cars went up 89 percent. This represents a small decrease in the number of passenger-car trips per passenger car from 3.15 to 3.05. These figures seem to indicate that the number of car trips increases roughly in proportion to the increase in the number of cars, and total person trips increase about as population does in the Washington area.

The number of trips by various vehicle types and modes of transportation together with the population and passenger-car ownership are shown in figure 1. The growth factors resulting from the changes between 1948 and 1955 are shown graphically in figure 2.

The increase of 89 percent in the number of passenger-car trips during the 7-year interval is rather high. It represents an average increase of almost 13 percent annually on a straight-line basis or about 9.5 percent if compounded annually.

This high rate of increase in the Washington, D. C. area, however, has the advantage of providing growth factors that are somewhat similar to the growth factors that have been forecast for about 25 years in some of the larger cities. For example, the growth factors for total vehicle trips as measured in Washington and those predicted for Detroit and Cleveland are shown on the following table:

Item	Washington	Detroit	Cleveland
Period covered	1948 to 1955	1953 to 1980	1952 to 1975
Over-all growth	1.66	1.67	1.79
Percent of zones with growth factors			
Less than 1.00	5	2	1
1.00-1.49	38	64	54
1.50-1.99	25	9	17
2.00-2.99	18	9	8
3.00-4.99	9	8	15
5.00-9.99	3	6	5
Over 10.00	2	2	0

1/ In this paper "trips by persons" includes trips by drivers of automobiles, taxis and trucks and by passengers in automobiles, taxis and mass transit vehicles. Walking trips and the small number of trips by passengers in trucks are not included.

Fig. I

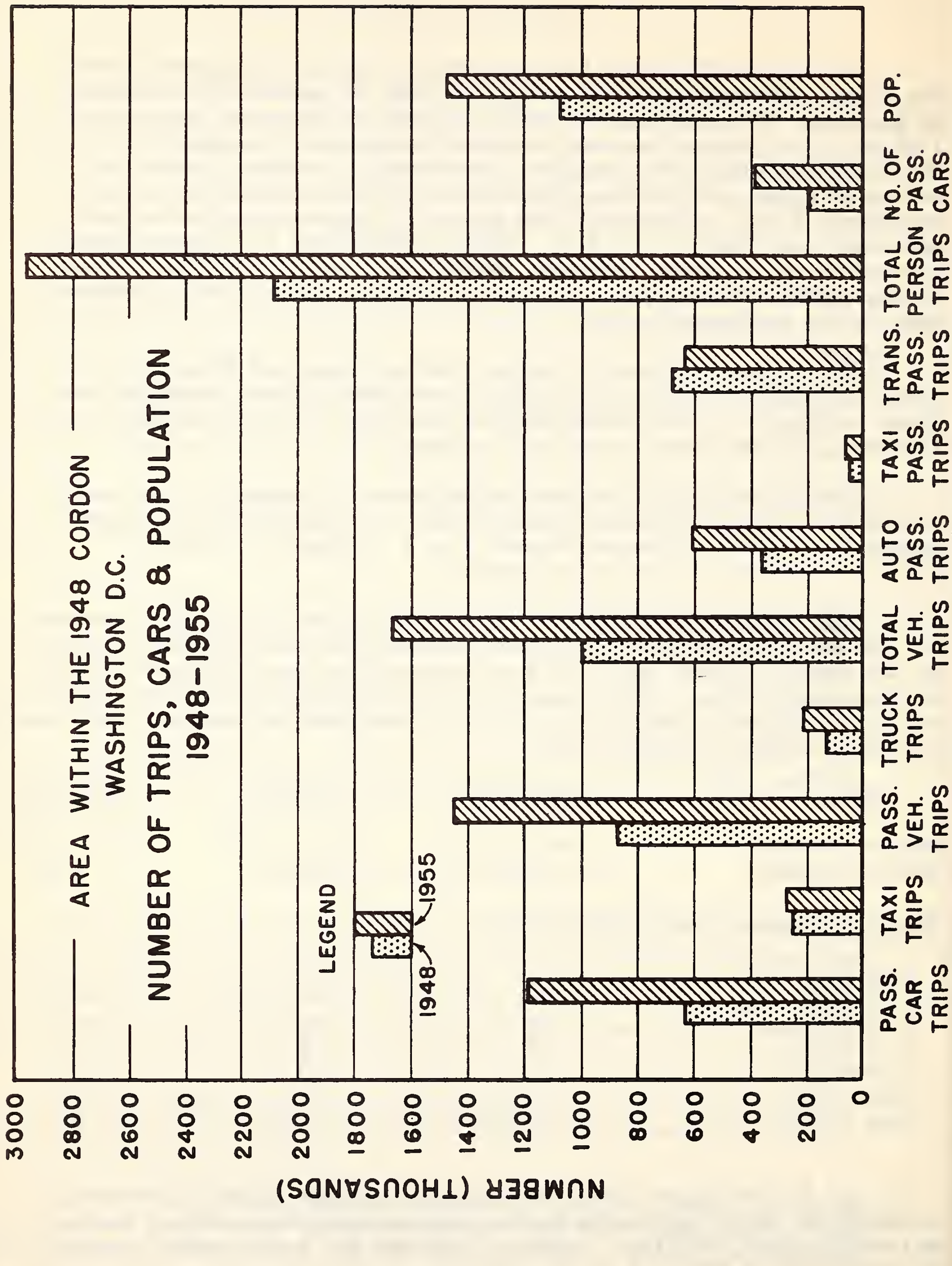
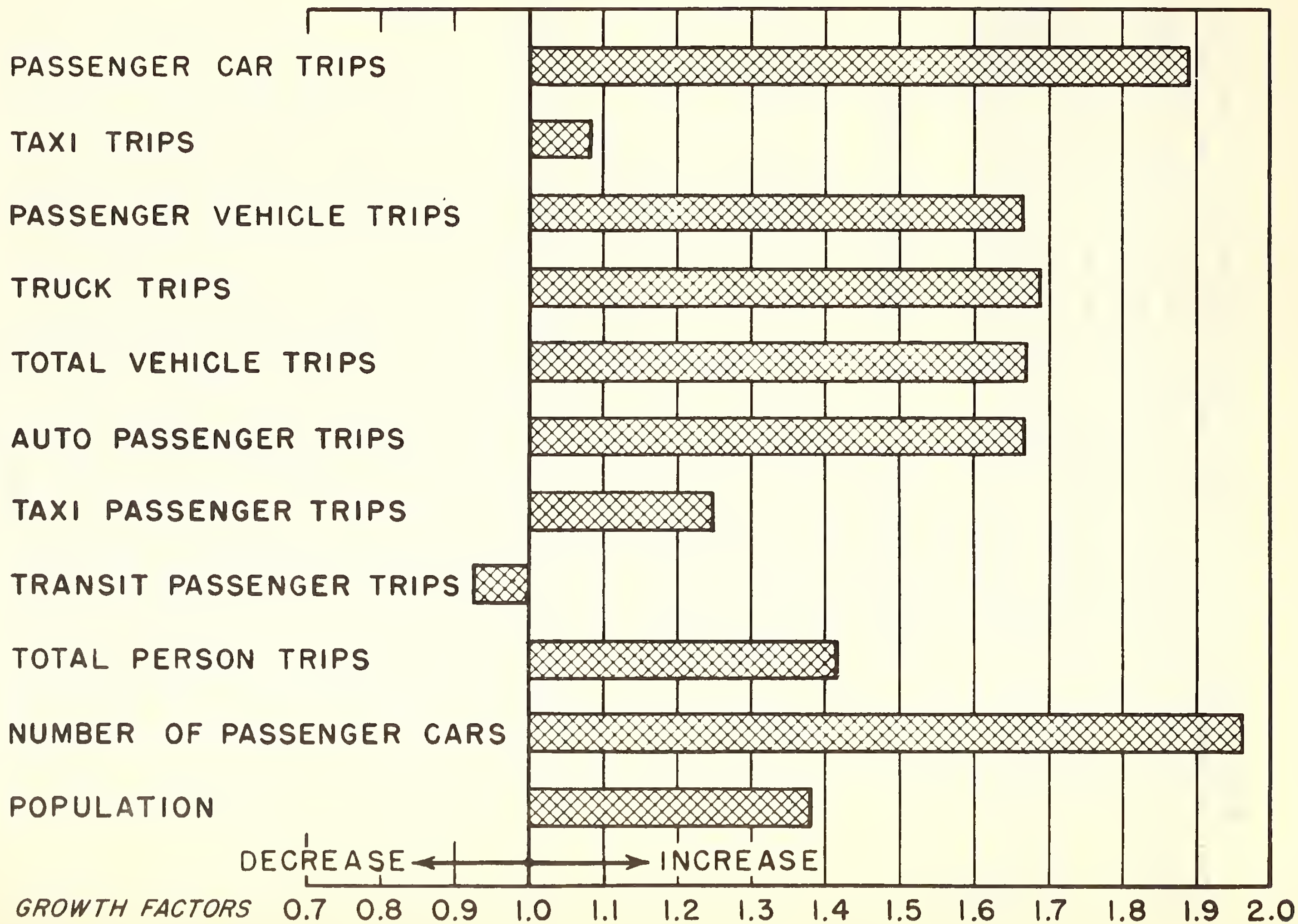

AREA WITHIN THE 1948 CORDON
WASHINGTON D.C.
NUMBER OF TRIPS, CARS & POPULATION
1948–1955
LEGEND
1948
1955
NUMBER (THOUSANDS)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
PASS. CAR TRIPS
TAXI TRIPS
PASS. VEH. TRIPS
TRUCK TRIPS
TOTAL VEH. TRIPS
AUTO PASS. TRIPS
TAXI PASS. TRIPS
TRANS. PASS. TRIPS
TOTAL PERSON TRIPS
NO. OF PASS. CARS
POP.

Fig. 2

AREA WITHIN THE 1948 CORDON
WASHINGTON D.C.

CHANGE FROM 1948 TO 1955



Thus while the test of the forecasting methods is confined to the growth of Washington, D. C., from 1948 to 1955, the actual growth factors are not entirely dissimilar to forecasts into the future for Detroit and Cleveland although the latter two are for longer periods of time.

In this study, the passenger-car trips and taxi trips were combined into one category of passenger-vehicle trips. The over-all growth factor for these trips was 1.67. As for individual zones, about 6 percent had fewer trip ends in 1955 than in 1948, and 50 percent had a growth factor smaller than 1.55. A more detailed distribution of the individual zone growth factors is as follows:

Growth factor	Percent of zones
Less than 1.00	6
1.00 to 1.50	40
1.50 to 2.00	23
2.00 to 3.00	19
3.00 to 5.00	7
5.00 to 10.00	2
Over 10.00	3

Methods of Forecasting Trips

The 1948 zone-to-zone trips were expanded to 1955 by various formulae and the predicted values compared with those obtained in the 1955 sample.

The actual methods are described as follows:

Nomenclature

T_{ij} = Observed 1955 trips between zone i and zone j

T_{ij}' = Calculated 1955 trips between zone i and zone j

T_{i-j}' = Calculated 1955 trips from zone i to zone j

T_{j-i}' = Calculated 1955 trips from zone j to zone i

t_{ij} = Observed 1948 trips between zone i and zone j

T_i = Summation of observed 1955 trip ends in zone i

t_i = Summation of observed 1948 trip ends in zone i

F_i = Growth factor for zone i = $\frac{T_i}{t_i}$

T = Summation of 1955 trip ends in entire area

t = Summation of 1948 trip ends in entire area

Nomenclature (Continued)

F = Growth factor for entire area = $\frac{T}{t}$

t_{ix} = 1948 trips between zone i and each of all other zones designated as zone x

F = Growth factor for zone x

Uniform Factor Method

The most simple method of expanding trips is to compute a single factor for the entire area and use it to multiply all zone-to-zone trips. This particular method is seldom used now, but because of its wide use in the past it was evaluated. Mathematically the expansion formula is as follows:

$$T_{ij}' = t_{ij} \times F$$

There is no possibility of successive approximations with this method, such as those used in the methods subsequently described.

Average Factor Method

In this method each of the 1948 zone-to-zone movements is multiplied by the average of the growth factors for the two zones involved as follows:

$$T_{ij}' = t_{ij} \frac{(F_i + F_j)}{2}$$

After the trips from one zone (i) to all other zones have been computed by this method, the sum of all trip ends in that zone as determined from this calculation (T_i') will probably not equal the actual 1955 trip ends in that zone (T_i). This discrepancy can be eliminated by a series of iterations producing successively closer approximations, as follows:

Let F_i' equal the factor needed to bring the calculated number of trip ends (T_i') to actual number (T_i) or $F_i' = \frac{T_i}{T_i'}$ and similarly $F_j' = \frac{T_j}{T_j'}$

Then for the second approximation,

$$T_{ij}'' = T_{ij}' \frac{(F_i' + F_j')}{2}$$

Similarly for a third approximation,

$$T_{ij}''' = T_{ij}'' \frac{(F_i'' + F_j'')}{2}$$

The process can be repeated until the F factors for a new iteration equal the limiting value of 1.00.

One of the inherent disadvantages of the average factor method is that the calculated trips into zones with higher-than-average growth factors generally total less than the predicted number of trips. Conversely the calculated trips into zones with lower-than-average growth factors total more than the predicted total of trips. This systematic bias of the predicted values could result in an inordinate number of approximations and may affect the accuracy of the method.

Detroit Method

A method to alleviate this difficulty was developed by Dr. Carroll's staff for the Detroit study. In this method they assumed that the trips from zone i will increase as predicted by F_i and will be attracted to zone j in the proportion $\frac{F_j}{F}$. The predicted trips from zone i to zone j can then be calculated as follows:

$$T_{i-j}' = t_{i-j} \frac{(F_i \cdot F_j)}{F}$$

Similarly the trips from zone j can be considered as increasing as predicted by F_j and will be attracted to zone i in the proportion $\frac{F_i}{F}$.

The predicted trips from zone j to zone i can then be calculated as follows:

$$T_{j-i}' = t_{j-i} \frac{(F_j \cdot F_i)}{F}$$

Therefore the number of trips between zone i and zone j is equal to the sum of the trips from i to j and from j to i or,

$$T_{ij}' = T_{i-j}' + T_{j-i}'$$

or,

$$T_{ij}' = t_{i-j} \frac{(F_i \cdot F_j)}{F} + t_{j-i} \frac{(F_j \cdot F_i)}{}$$

$$= (t_{i-j} + t_{j-i}) \frac{(F_i \cdot F_j)}{F}$$

$$= t_{ij} \frac{(F_i \cdot F_j)}{F}$$

As in the case of the average factor method the calculated trip ends in a particular zone will probably not equal the predicted trip ends in that zone. Therefore, new F factors can be determined as follows:

$$F_i' = \frac{T_i}{T_i'}$$

$$F_j' = \frac{T^j}{T_j'}.$$

and a second approximation can be calculated as follows:

$$T_{ij}'' = T_{ij}' \frac{(F_i' \cdot F_j')}{F'}$$

This same procedure can be used to calculate a third and subsequent approximations until the new F factors equal the limiting value of 1.00.

Fratar Method

The first method in which the iterative process was used in predicting future trips was developed by Thomas J. Fratar in connection with the forecast for Cleveland, ohio. Fratar considers that the distribution of the trips from any zone i is proportional to the present movements out of zone i modified by the growth factor of the zone to which these trips are attracted. The volume of the trips, however, is determined by the expansion factor of zone i.

Mathematically this method is developed as follows:

If the trips between zones i and j, as calculated by considering all trips from zone i are represented by the sumbol $T_{ij(i)}'$ and those as calculated by considering all of the trips from zone j by the symbol $T_{ij(j)}'$, then

$$(1)\quad T_{ij(i)}' = t_{ij} \cdot F_j \cdot \frac{\sum(t_{ix} \cdot F_i)}{\sum(t_{ix} \cdot F_x)}$$

Noting that $\sum t_{ix} \cdot F_i$ can also be written as $F_i \cdot \sum t_{ix}$ then equation (1) can be written as,

$$(2)\quad T_{ij(i)}' = t_{ij} \cdot F_j \cdot F_i \cdot \frac{\sum t_{ix}}{\sum(t_{ix} \cdot F_x)}$$

The last term in equation (2) basically represents the reciprocal of the average attracting pull of all other zones on i. We have labeled it the "Location" or "L" factor since it is somewhat dependent on the location of the zone with respect to all other zones. Thus since

$$(3)\quad \frac{\sum t_{ix}}{\sum(t_{ix} \cdot F_x)} = L_i$$

Equation (2) can be rewritten as

$$(4)\quad T_{ij(i)}' = t_{ij} \cdot F_j \cdot F_i \cdot L_i$$

Then for all trips from zone j, it can similarly be shown that

$$(5)\quad T_{ij(j)}' = t_{ij} \cdot F_i \cdot F_j \cdot L_j$$

Thus the trips between zone i and zone j have been computed twice--once for all trips out of zone i and once for all trips out of zone j. The most probable value is an average of the two computations or,

$$(6)\quad T_{ij}' = \frac{T_{ij(i)}' + T_{ij(j)}'}{2}$$

Substituting the identities from equations (4) and (5) into equation (6) and factoring out the common terms, the final equation is developed

$$(7) \quad T_{ij}' = t_{ij} \cdot F_i \cdot F_j \cdot \frac{(L_i + L_j)}{2}$$

After all the zone-to-zone trips have been computed by this formula, the calculated trip ends in a particular zone will probably not agree with the predicted trip ends in that zone. Therefore new factors can be calculated as follows:

$$F_i' = \frac{T_i}{T_i'}$$

$$F_j' = \frac{T_j}{T_j'}$$

$$L_i' = \frac{\sum T_{ix}'}{\sum T_{ix}' \cdot F_x'}$$

$$L_j' = \frac{\sum T_{jx}'}{\sum T_{jx}' \cdot F_x'}$$

A second approximation can then be calculated as follows:

$$T_{ij}'' = T_{ij}' \cdot F_i' \cdot F_j' \cdot \frac{(L_i' + L_j')}{2}$$

The same procedure can be used for subsequent approximations until the new F factors equal the limiting value of 1.00.

The Problem of Evaluation

With the Washington area divided into 254 zones, the number of possible zone-to-zone movements is $\frac{N(N + 1)}{2}$ = 32,385. 2/ It was expected that some of the zone-to-zone movements would be zero in 1948 and 1955 and would not need to be computed. However, it was estimated conservatively that perhaps 30,000 of the 1948 zone-to-zone movements would require expansion to 1955.

To determine whether the accuracy of the prediction was influenced by vehicle type or mode of transportation, the trips were separated by mode of travel into six categories: Passenger-vehicle trips, truck trips, total vehicle trips, transit-passenger trips, auto-passenger trips, and total trips by persons; and each group was expanded separately.

Expanding each of the 30,000 zone-to-zone trips made in 1948 would be almost meaningless unless some method of summarizing the comparison to the 1955 survey movements had been determined. The most obvious answer to this problem was to subtract the computed number of trips from the reported number of 1955 trips, square the difference and accumulate the result. The sum of the differences squared could then be used to calculate the root-mean-square error of the number of trips as expanded from the 1948 data.

This summary, however, had a serious disadvantage in that the actual volume of zone-to-zone trips varies from zero to several thousand. A root-mean-square error could be inordinately affected by the relatively few large movements. Similarly, if the difference were converted to a percentage of the 1955 actual movement and the root-mean-square of the percentage computed, the result could be as greatly affected by the small movements that probably lack sufficient stability to provide meaningful information. It was therefore decided to stratify the 1948 movements by volume classes, thus: by volumes of tens to 100, by volumes of hundreds to 1,000, and all volumes over 1,000. The numerical root-mean-square error was then computed for each volume class and the percentage error for the class was obtained from the ratio of the numerical root-mean-square to the average 1955 volume. The proportion of all 1955 volumes in each volume class was then determined and each of the percentage errors was weighted by the proper proportion to obtain the over-all percentage error.

The over-all percentage error as described above was regarded as the proper measure to evaluate the various predictive formulae. In addition, the accuracy of larger movements could be measured by an extrapolative process in which the number of average zone-to-zone movements required to make up a larger volume was determined and the basic error was divided by the square root of the number of movements required.

In addition to the computation described above, it was desirable to know the root-mean-square error for each of the zones so that the error can be related to the growth factor of the individual zones. Therefore, the

2/ Zone-to-zone movements as used in this article also include intrazone movements.

difference between the expanded 1948 and the 1955 movements squared was accumulated for each of the zones. It was considered likely that from this computation any inordinate error found in a particular zone could be recognized.

As has been previously explained, it is possible to carry the average factor method, the Detroit method, and the Fratar method through a number of iterations to produce successively closer approximations. To be reasonably certain that this process was continued a sufficient number of times, it was decided to calculate 10 successive approximations by each method.

Need for an Electronic Computer

It has been estimated that roughly 25 million computations would be required for this test. On the very optimistic basis that one computation can be completed in 10 seconds, using ordinary desk calculators, the project would require some 30 man-years for completion. Clearly this is not feasible. However, with electronic computers, the time required can be reduced enormously.

The three methods that use iterations are similar in that the input for the first calculation is made up of the original data, the output of this calculation and each successive iteration becomes the input of the next iteration and so on until 10 calculations have been made if necessary for satisfactory closure. In addition each iteration of the Fratar method requires two passes of the input--one to determine the L factor and one to make the required expansion. Thus, the 30,000 zone-to-zone movements have to be processed 42 times, including the one pass of the data required to obtain the original growth factors.

In deciding upon the particular type of computer to be used, the first problem was to decide whether to use one with card input and output, or one with tape. The card type would require about 200 hours of computer time provided sufficient memory were available. With tape, only about 10 hours of computer time, or less would be required, again assuming sufficient memory, so obviously the tape-using type was preferable. In the actual test, 30 hours of computer time were used principally due to additional tests on large zone groupings.

Computer Characteristics

Computer problems in general fall into two categories, viz, data-processing problems and computation problems. For instance, a problem of testing forecasting methods, as discussed herein, requires a great deal of input and output but rather simple internal operations and is properly classified as a data-processing problem. On the other hand computing such things as log tables or trigonometric functions requires much computation but very little input and output.

The problem then was to select a machine designed to process data with good "read and write" characteristics and with a large memory. We were fortunate in being able to arrange for part-time use of an IBM 705 machine which met all these requirements very well. The machine had a core memory of 40,000 characters. The memory capacity of computers is sometimes reported in "characters" and sometimes in "words." In computer terminology, a "character" may be a digit, a letter or a symbol, while a "word" consists of a group of characters. In some computers the word is of a constant length and in other computers the word length may be varied at the option of the programer. The computer used was a variable-word-length machine and the core-memory capacity is therefore given in characters rather than words.

The machine was equipped with two tape-record coordinators, more commonly referred to as buffers. The purpose of the buffers is to shorten the reading and writing time. Each buffer has a core storage capacity of 1,024 characters. The buffers are loaded from the tape units, and when the computer requires more data it obtains it at electronic speed from the buffer. As soon as the buffer is called upon for data, the tape unit feeding it begins to accelerate, so that by the time the buffer is empty the tape unit has begun to refill it with the next record to be processed. The same process works essentially in reverse for output. Thus the machine can go on with other work while records are being fed into and out of the buffers.

The 1,024-character capacity of the buffers also allows a number of card records to be grouped so that when the buffer calls on the tape units for data, one tape record can receive information from a number of cards without exceeding the buffer capacity. The program for this study was designed to have the machine read or write the equivalent of 24 cards of information per reading or writing cycle. As it turned out in production, the computer took a longer time to process the data on the 24 cards than was required to fill or empty the buffers so that the machine never had to wait for data, and all reading or writing time was essentially "free."

The 705 is a decimal machine, meaning that the entire content of memory is in condition always to be printed out as alpha-numeric information directly without conversion from binary to decimal. The machine performs internal operations at an average rate of 8,300 per second.

Preparation of Program

In programing the problem the first difficulty was one of memory space, in spite of the large amount available. It was necessary to overlap the program and resort to external tape storage. Even so it was necessary to split the problem into two parts. All of the vehicle types, viz, passenger cars, trucks, and total vehicles, were handled in the first run. The second run processed the person trips: auto passengers, transit passengers, and total persons. The same basic program was used for both runs, however.

It was necessary to prepare a preliminary program in order to group the single card records into groups of 24, which is the maximum number of cards within buffer capacity, and to separate them into vehicle or person categories. Included in this preliminary program was an editing routine, a volume-classification routine, and a check-sum routine. The editing routine rejected any cards with alphabetic information, i. e., over-punches, inconsistent zone numbers, etc. The volume classification routine classified the 1948 volumes of trips into 20 volume classes. The check-sum routine summed all the volumes by modes and zones and compared the totals with a 254-card summary deck prepared independently. The preliminary program also permitted the preparation of the main program while the input data were being compiled. Any changes in the arrangement of the data taken from the cards could be taken care of in the first program without affecting the main program.

The program was designed to have all the final output written on tape for subsequent printing. It was found that the machine would be slowed down a great deal if a printer were connected "on line." As originally designed, there was one line of printed information for each of 20 volume classes times 6 modes of travel, one line for each of 254 zones times 6 modes, and one line for each over-all citywide volume for each of the 6 modes. For all of the methods tested, with their iteration, this amounted to 52,800 printed lines, or almost 1,760 pages--a real data-processing problem.

Test Results

The initial run of the computer was made for vehicle trips by passenger cars, trucks, and total vehicles. The 1948 zone-to-zone movements were projected to 1955 by a uniform factor, by the average factor method, by the Detroit method, and by the Fratar method. These projected or "forecasted" results were compared with the measured 1955 volumes and the differences were squared, accumulated, and used to compute a root-mean-square error for the average movement, for the various volume classes and for the individual zones.

These results are shown in table 1 for the three types of vehicle trips. So far as number of trips is concerned, the errors are not large, considering that the sample was as small as 1 in 30 for an important part of the data, and in no case larger than 1 in 10. On a percentage basis, however, the errors are very large.

When the results of the first computer run became available, the question immediately arose whether the errors were primarily attributable to the forecasting methods being tested or to the preponderance of low-volume zone-to-zone movements, which are known to lack accuracy or stability at the sample rates used.

Table 1.--Root-mean-square error in the number of zone-to-zone trips forecasted for 1955 from 1948 data, compared to 1955 survey results, expressed in number of trips and percentage

Approximation number	Numerical RMS error				Percent RMS error 1/			
	Uniform factor	Average factor	Detroit	Fratar	Uniform factor	Average factor	Detroit	Fratar
	Passenger cars 2/							
1	165	133	234	140	151	136	192	140
2		132	129	131		136	133	134
3		133	148	132		136	143	134
4		134	129	132		137	133	135
5		134	136	132		137	137	135
6		135	131	132		138	134	135
7		135	133	132		138	135	135
	Trucks 2/							
1	18	57	59	55	163	160	172	162
2		55	58	55		160	161	161
3		55	55	55		161	163	161
4		55	56	55		162	161	161
5		55	55	55		162	162	161
6		55	55	55		162	161	161
7		56	55	55		162	162	161
	Total vehicles 2/							
1	174	137	229	138	141	124	175	125
2		133	131	130		122	120	120
3		133	144	131		121	128	121
4		133	129	131		122	119	121
5		133	134	131		122	122	121
6		133	130	131		122	120	121
7		133	132	131		122	121	121

1/ Calculated by determining the error in the various volume groups and weighting the error in each group in proportion to the percentage of all trips in that group.

2/ Calculated on the basis of number of zone-to-zone movements that had more than 0 trips in either 1948 or 1955.
Passenger cars average zone-to-zone volume = 84;
Trucks average zone-to-zone volume = 28;
Total vehicles average zone-to-zone volume = 90.

This problem was attacked by two methods. One was by a systematic enlargement of the zones to increase the volume of the zone-to-zone movements and then testing these larger volumes through the computer program. The other method was to determine the percentage distribution of the zone-to-zone trip volumes within the city and by statistical techniques to determine the accuracy that might be expected in the original trip expansion. If the 1948 zone-to-zone trip volumes as expanded from the sample were unreliable, the error would be carried on into the forecast data, and if the 1955 expanded volumes were also unreliable, the result could be to compound the effect of the errors due to sample variability in comparing the forecasts with the 1955 data.

Enlarging Zones

Inasmuch as zone boundaries are chosen from land-use and geographic features, the number of trip ends in each zone is not uniform. In this study the variability was intensified by the fact that the area had to be rezoned so that it would be identical in both years, and the trip ends in the individual zones vary over wide limits. For example the number of 1948 passenger-vehicle trip ends averaged 6,900 per zone but varied from as little as 193 to as much as 59,870. As the initial step, therefore, adjacent zones were combined until each zone group had a minimum of 10,000 passenger-vehicle trip ends in 1948. To minimize the effect of sample variability on the errors, this procedure was repeated to accumulate a minimum of 20,000 trip ends per zone group, and again to accumulate a minimum of 30,000 trip ends per group, then to divide the entire area into 7 groups and finally into 2 groups.

The number of zones in these successive groupings, the number of 1948 passenger-car trip ends in the average zone, and the average number of area-to-area trips are as follows:

Number of areas	Number of trip ends per area: Minimum	Number of trip ends per area: Average	Number of area-to-area possibilities	Average number of area-to-area trips
254 zones	193	6,900	32,385	27
122 groups	10,000	14,400	7,503	116
66 groups	20,000	26,600	2,211	394
49 groups	30,000	35,800	1,225	711
7 groups	214,305	250,000	28	31,092
2 groups	731,000	870,000	3	290,192

Test Results of Enlarged Zones

The results of tests of each forecasting procedure for the various zone groupings are shown in table 2. As can be seen from this table, the average-factor method, the Detroit method, and the Fratar method each reach essentially the same minimum error although the Fratar method reaches this minimum in the second approximation, whereas more iterations are generally required for the other methods.

Table 2.--Root-mean-square error of the forecasted 1955 passenger car trips for the 254 zones and for different zone groupings

Approximation number	254 zones Error in trips		122 groups Error in trips		66 groups Error in trips		49 groups Error in trips		7 groups Error in trips	
	Number	Percent 1/	Number	Percent 1/	Number	Percent 1/	Number	Percent 1/	Number	Percent 1/
Uniform Factor Method										
x	165	151	415	98	499	57	747	49	19,641	38
Average Factor Method										
1	133	136	244	77	458	49	655	42	10,180	20
2	132	136	204	72	364	44	542	37	8,300	16
3	133	136	196	71	344	43	517	36	7,810	15
4	134	137	194	71	338	42	509	35	7,690	15
5	134	137	193	71	337	42	507	35	7,540	15
6	135	138	193	71	336	42	506	35	(2/)	
7	135	138	193	71	336	42	506	35		
Detroit Method										
1	234	192	388	89	720	64	871	51	10,300	20
2	129	133	228	74	396	46	543	37	8,960	17
3	148	143	299	74	344	42	504	35	7,700	15
4	129	133	194	70	337	42	484	34	7,510	15
5	136	137	196	70	320	41	478	34	7,500	15
6	131	134	189	70	326	41	480	34	7,570	15
7	133	135	190	70	319	41	476	34	7,480	14
Fratar Method										
1	140	140	205	71	339	42	498	35	7,360	14
2	131	134	188	70	322	41	480	34	7,460	14
3	132	134	188	70	322	41	478	34	(2/)	
4	132	135	188	70	321	41	479	34		
5	132	135	188	70	322	41	478	34		

1/ A weighted percent error obtained by determining the percent error in each volume class and weighting this error by the proportion of trips in that volume class. Not applicable for the 7 zone group because all volumes were in the largest volume class.
2/ No further iterations required because new F factor for all zones was 1.00.

The minimum percentage error, by any of the methods tested after any number of iterations, for the various zone groups and the average number of area-to-area passenger-car trips were as follows:

Number of areas	1948 average number of area-to-area trips	Minimum percent error
254 zones	27	133
122 groups	116	70
66 groups	394	41
49 groups	711	34
7 groups	31,092	14
2 groups	290,192	11

In the case of the 2-group division a second test was made by dividing the area with a line roughly at right angles to the first. The minimum percent error for this second grouping was the same as that for the first, to the nearest percent (11 percent).

The relationship between average area-to-area trip volume and the minimum percent error is shown in figure 3. As the minimum error for the three iterative methods is about the same, the chart can be considered as applicable to any one of them. This chart is difficult to interpret because part of the error is due to sample variability and part is due to the projection method being tested. Differences in sampling rate introduce a further complication. In the 1948 survey the sampling ratio was 1:20 throughout the area, while in the 1955 survey it was 1:30 for the District of Columbia and 1:10 for the Maryland and Virginia suburbs. However, the curve should give some indication of the error to be expected in using any of the three iterative methods where the sampling rate is about the same as the average for the two Washington surveys, that is, about 5 percent.

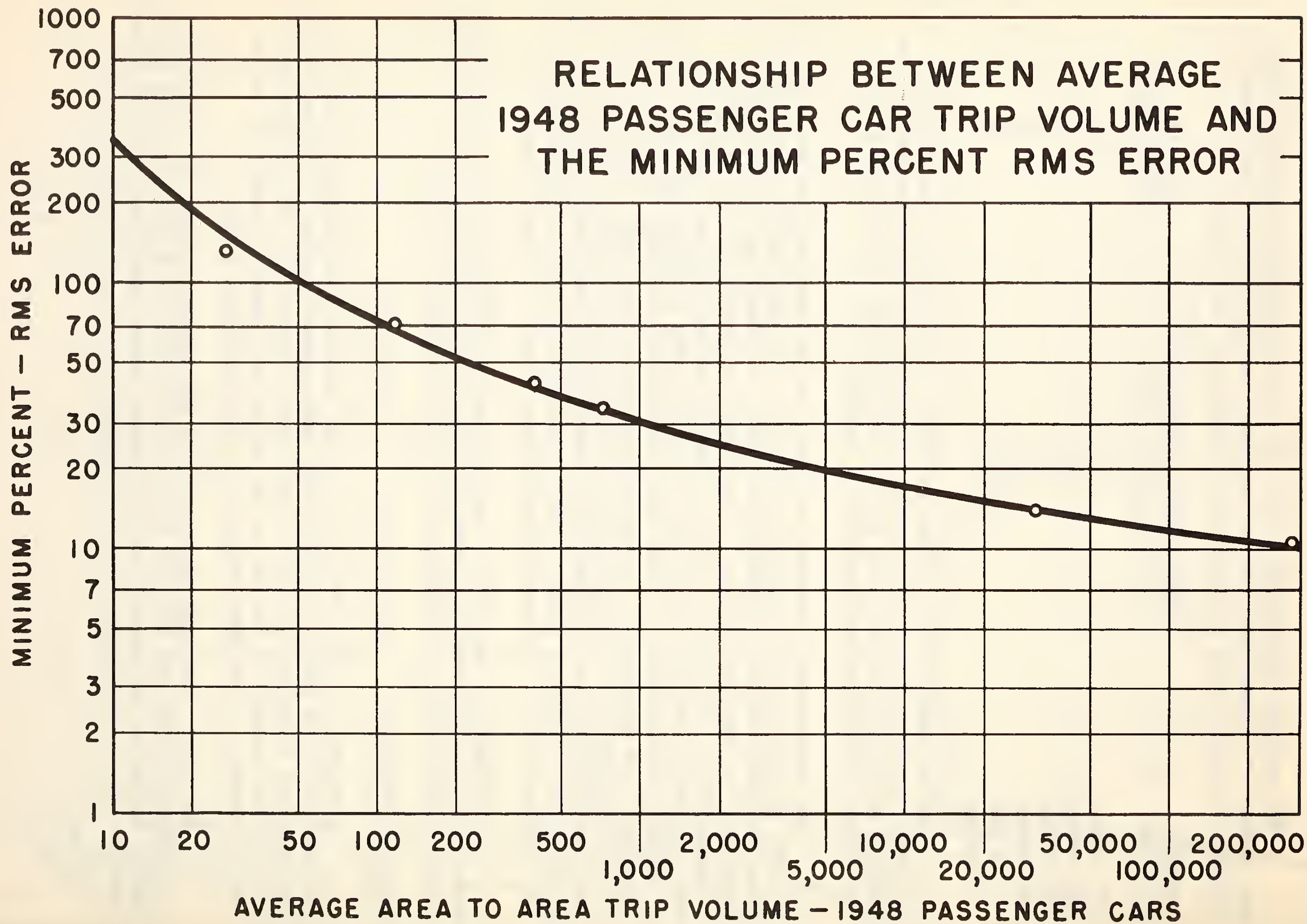
The shape of the curve suggests that it will level off at about 10 percent. In other words an error of about 10 percent seems to be inherent in the methods tested, regardless of size of sample or areas.

Rate of closure

A measure of the efficiency of the various forecasting methods is the rapidity with which the individual zone growth factors converge toward the limiting F factor of 1.00 in successive iterations. The difference between the computed F factor at the end of an iteration and 1.00 is the factor residual error that remains in the individual zones.

The factor residual error for the 254 zones is shown in the following tabulation for the various iterations of the three methods. The first column indicates the method and the second column indicates the approximation number. The third column shows the percent of the zones that have no

Fig. 3


RELATIONSHIP BETWEEN AVERAGE
1948 PASSENGER CAR TRIP VOLUME AND
THE MINIMUM PERCENT RMS ERROR
MINIMUM PERCENT — RMS ERROR
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
10
20
50
100
200
500
1,000
2,000
5,000
10,000
20,000
50,000
100,000
200,000
AVERAGE AREA TO AREA TRIP VOLUME — 1948 PASSENGER CARS

residual error (new F factor = 1.00) at the end of the approximation shown in the second column. The fourth column indicates the percent of zones with a residual error less than 0.01 (new F factor between 0.99 and 1.01). The next four columns similarly show the percent of zones with residual errors less than 0.02, 0.03, 0.05, and 0.10. The last column shows the percent of zones with residual errors greater than 0.10 (new F factor less than 0.90 or more than 1.10).

Method	Approximation No.	Percent of zones with a factor residual error of--						
		0.00	Less than 0.01	Less than 0.02	Less than 0.03	Less than 0.05	Less than 0.10	0.10 and over
Average factor	1	1	8	11	17	26	47	53
	2	6	15	24	35	50	75	25
	3	10	30	44	55	77	93	7
	4	19	47	71	84	98	99	1
	5	33	70	88	93	98	99	1
	6	49	84	92	94	98	100	0
	7	64	92	97	99	100	100	0
Detroit	1	2	4	9	14	23	44	56
	2	1	3	11	15	22	57	43
	3	4	13	25	37	63	95	5
	4	5	18	38	58	95	98	2
	5	10	36	68	93	98	99	1
	6	16	62	95	97	98	100	0
	7	28	85	98	99	100	100	0
	8	37	96	99	100	100	100	0
Fratar	1	6	20	33	54	68	79	21
	2	60	97	100	100	100	100	0
	3	98	100	100	100	100	100	0
	4	99	100	100	100	100	100	0

As can be seen from this table the Fratar method is extremely efficient in its rate of closure. Since the F factor must be obtained for each new iteration and since these new F factors may be easily summarized, it is suggested that they be used to indicate the desirability for additional iterations.

Number of iterations required

From the tests that have been run, the minimum root-mean-square error has always been reached in the second approximation by the Fratar method. By the other methods, however, this minimum error may not be reached until the fourth or fifth approximation. There is also a possibility that an unusual set of growth factors will develop that will not close as rapidly as those occurring in the test data.

Considering the division of the Washington, D. C., area into 49 zone groups with a minimum of 30,000 passenger-car trip ends per group, the factor residual error was accumulated for all groups at the end of each iteration. The accumulated residual error was then divided by the number of groups to obtain the average residual error per group. This average residual error was then related to the RMS error already computed for each approximation. The following table indicates the results:

Approximation No.	Average factor: Average residual error	Average factor: RMS error	Detroit: Average residual error	Detroit: RMS error	Fratar: Average residual error	Fratar: RMS error
		(percent)		(percent)		(percent)
1	0.084	42	0.123	51	0.035	35
2	.034	37	.070	37	.003	34
3	.014	36	.032	35	.001	34
4	.007	35	.022	34	(1/)	34
5	.003	35	.014	34	(1/)	34

To be reasonably certain that greater accuracy cannot be obtained with additional iterations, it is suggested that iterations be continued until the average residual error per zone is less than 0.01.

The computer time required for each method, however, is not uniform but is approximately related to the complexity of the method. During the test, the computer time as recorded for each iteration of each method and adjusted proportionately to a common base of 10,000 zone-to-zone movements is as follows:

Computer time per iteration of 10,000 area-to-area movements

Average factor method	-	6 minutes
Detroit method	-	9-1/2 minutes
Fratar method	-	12 minutes

From the above table, the computer time required for the average factor method is half that required for the Fratar method. These times,

1/ Less than 0.001

however, include the computer time needed to develop and store the various statistical measures. In an ordinary forecasting procedure these measures would not be required and the above times would be reduced by a constant but indeterminate amount. The average factor method should therefore require something less than half the time per iteration required by the Fratar method.

Since the RMS error for the average factor method at the end of four approximations is about equal to the RMS error for the Fratar method at the end of two approximations, the over-all computer time required for equal RMS accuracy is about the same. However, the rate of closure of the Fratar method is more than twice as rapid as the average factor method and it would therefore appear to be the preferred method.

Percent RMS Error for Accumulated Volumes

The data presented thus far have to do only with the error for the area-to-area volumes. As has been shown, the average volume between zones of the size ordinarily used is relatively small and the percent root-mean-square error is, roughly speaking, correspondingly large.

In actual practice, the individual zone-to-zone volumes are assigned to the highway network, and therefore, each portion of the highway network represents an accumulation of zone-to-zone volumes. The volumes assigned to the highway network are our primary concern. The errors to be expected in such accumulated volumes can only be determined from actual tests and these have not yet been made. However, some indication of the magnitude of the errors to be expected can be obtained from purely theoretical considerations.

From a statistical standpoint, if the percent error of an average zone-to-zone volume is X, the percent error of a group of average zone-to-zone volumes is $\frac{X}{\sqrt{N}}$ where N is the number of individual zone-to-zone movements in the group. By dividing 10,000 by the average zone-to-zone volume for each of the zone groupings, the number of zone-to-zone movements (N) required to accumulate to a volume of 10,000 can be determined and the percent RMS error of the group can therefore be calculated.

The above relationship holds true only if the mean error of the group is zero. If the movements, however, are heavily weighted by trips from an individual zone, as they would be in the case of ramp volumes, the factor residual error (as previously explained) may be appreciable in the early iterations.

For example, if the trips on a ramp are essentially from two zones and these two zones have an average F factor for the next iteration of 1.30, the summation of trips into and out of the zones at the end of the present iteration are too low. The total number of trips for a group of zone-to-zone movements from these zones, therefore, will have a tendency to approach a volume which should be increased by 30 percent. To take this error into

account, the root-mean-square of the residual errors was determined for each iteration of each method. The number of zones required to provide a volume of 10,000 was determined and the root-mean-square residual error was added to the RMS error for individual zone-to-zone movements by taking the square root of the sum of the squares of the two errors to determine the total error. The results of this test are shown on figure 4.

If we can assume that this chart has some validity with reference to the problem, it indicates that the error for a volume of 10,000 trips is within acceptable limits and that it does not make too much difference what size zone group is used although a minimum error was obtained for the zone grouping which had 10,000 trip ends per group. Manifestly, however, this conclusion is dependent, to a substantial degree, on statistical inference and should be subjected to an actual test before it can be fully accepted.

Distribution of Zone-to-Zone Volumes

Even though the accumulated volumes of 10,000 or more apparently will have errors of rather modest proportions, it is desirable to inquire into the reasons for the inaccuracies of the movements between zones as they were originally planned and subsequently enlarged.

The test program was set up to count the number of zone-to-zone movements in each of several 1948 volume classes as previously described. This procedure was followed for the original 254 zones and for the subsequent groupings to 122 areas, 66 areas, and 49 areas.

The results of this test are shown on figure 5 for passenger cars (including taxis). Note that about 93 percent of the movements between the 254 zones have a volume of less than 100. When the number of areas was reduced to 122, about two-thirds of the area-to-area movements were less than 100; with 66 areas about one-fourth of the movements were less than 100; and with 49 areas about 10 percent were less than 100. Also note that the number of area-to-area movements which are less than the mean exceeds the number that are greater than the mean showing that the distribution is skewed. This is true for each of the zone groups although slightly less pronounced as the number of areas is successively decreased.

The test program also permitted the determination of the percent of the 1955 trips that were accumulated in each of the 1948 volume classes. The results of this test are shown in figure 6. Note that 50 percent of the 1955 passenger-car trips were made between zone pairs that, in 1948, had a volume of less than 100 passenger-vehicle trips per day. Values for other zone groups and other 1948 volumes can be read from the chart.

In summation then, the preponderance of zone-to-zone movements within a metropolitan area is exceeding small but because of the large number of such movements, they do, in the aggregate, account for a substantial portion of the present or predicted trips.

PERCENT ERROR TO BE EXPECTED FOR 10,000 TRIP VOLUMES BASED ON THEORETICAL CONSIDERATIONS

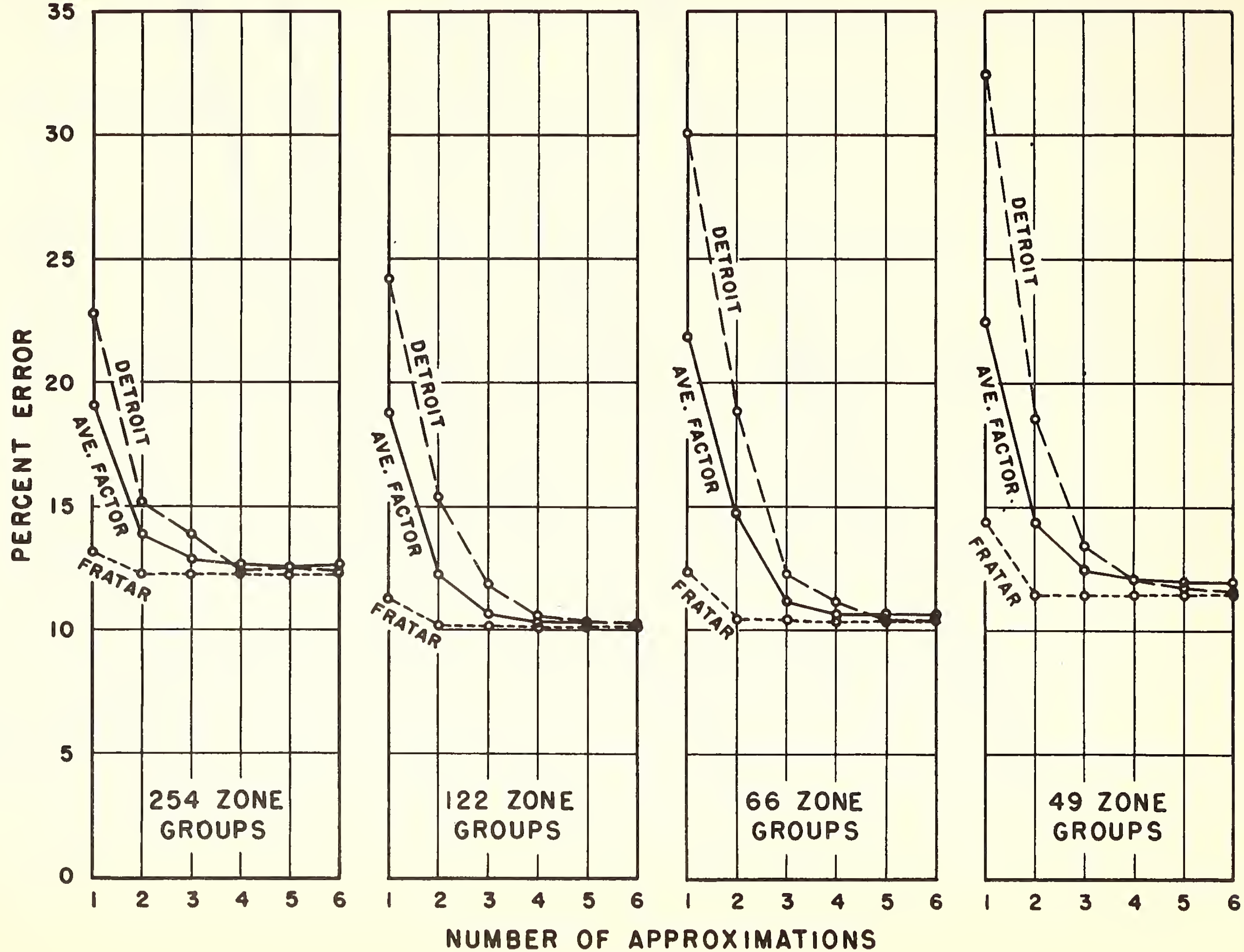


Fig. 5

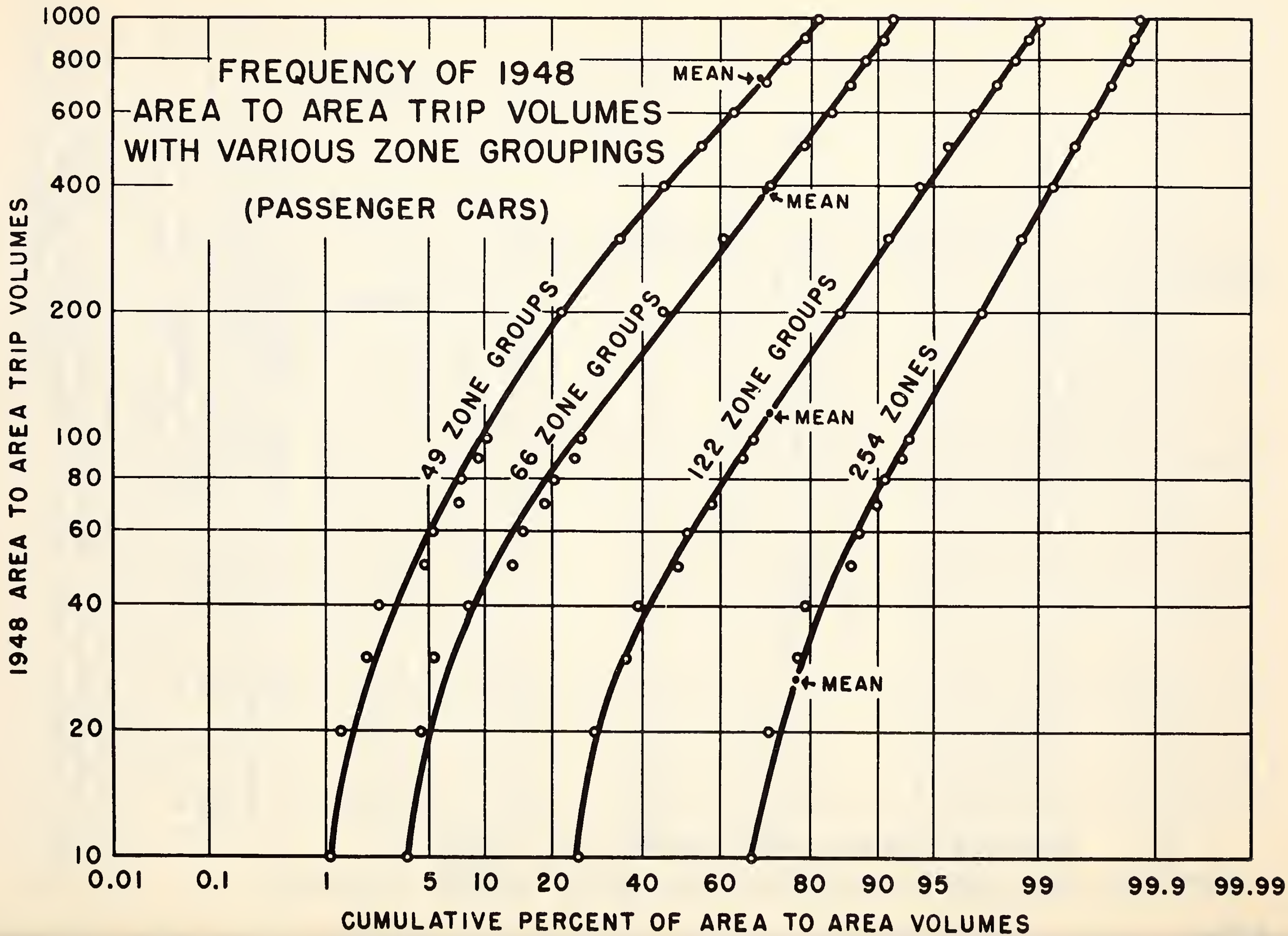
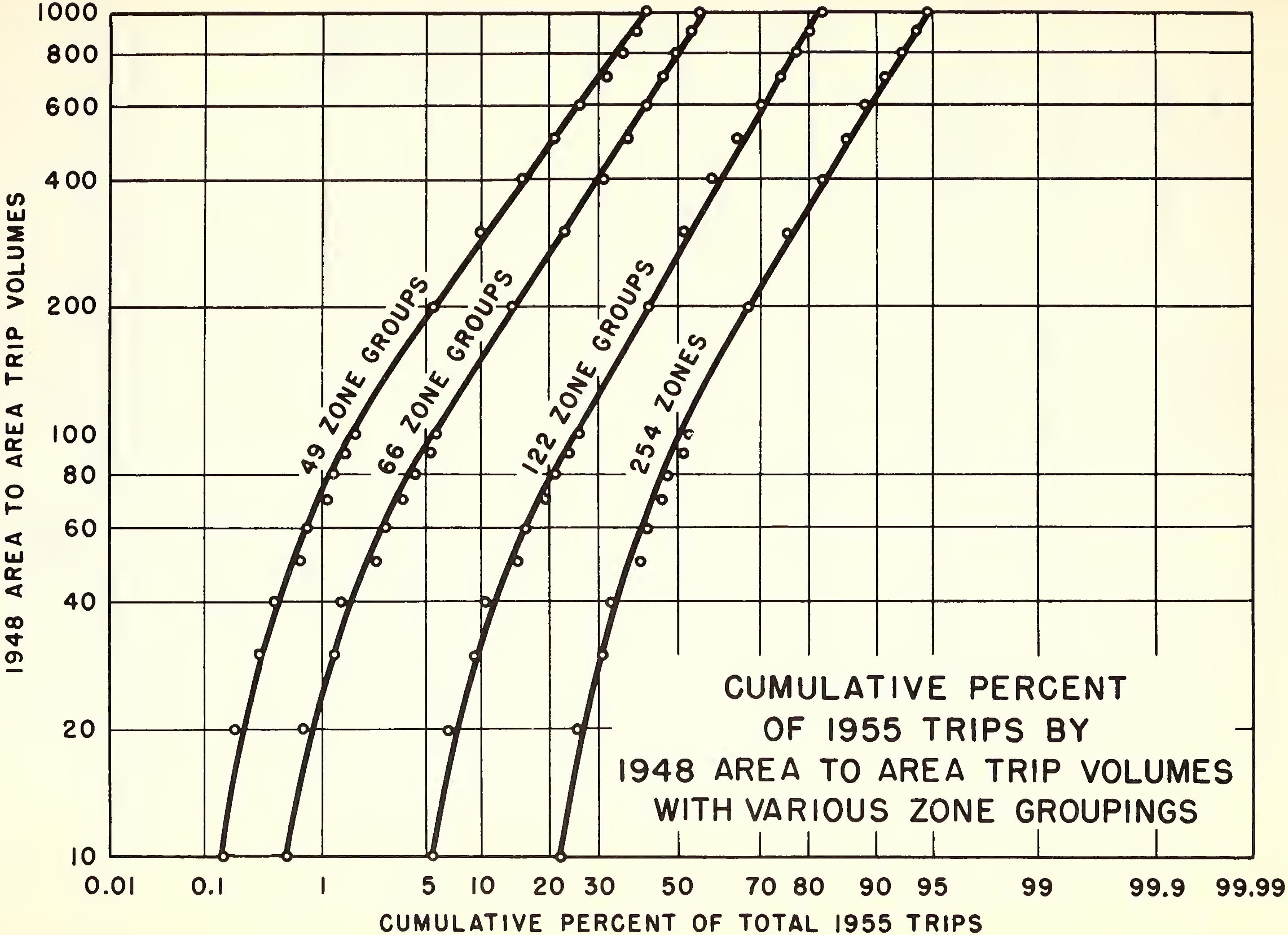

FREQUENCY OF 1948
AREA TO AREA TRIP VOLUMES
WITH VARIOUS ZONE GROUPINGS
(PASSENGER CARS)
1948 AREA TO AREA TRIP VOLUMES
1000
800
600
400
200
100
80
60
40
20
10
CUMULATIVE PERCENT OF AREA TO AREA VOLUMES
0.01
0.1
1
5
10
20
40
60
80
90
95
99
99.9
99.99
49 ZONE GROUPS
66 ZONE GROUPS
122 ZONE GROUPS
254 ZONES
MEAN
MEAN
MEAN
MEAN

Fig. 6


CUMULATIVE PERCENT
OF 1955 TRIPS BY
1948 AREA TO AREA TRIP VOLUMES
WITH VARIOUS ZONE GROUPINGS
49 ZONE GROUPS
66 ZONE GROUPS
122 ZONE GROUPS
254 ZONES
1948 AREA TO AREA TRIP VOLUMES
1000
800
600
400
200
100
80
60
40
20
10
CUMULATIVE PERCENT OF TOTAL 1955 TRIPS
0.01
0.1
1
5
10
20
30
50
70
80
90
95
99
99.9
99.99

Prediction Error as Related to Zone-to-Zone Volume

There is, of course, no a priori reason why small zone-to-zone volumes cannot be forecast with accuracy equal to large zone-to-zone volumes. The converse would likely seem true, that the forecast error should be independent of the volume.

However, there is a priori probability that the error in the expanded number of trips from a "sample" survey is inversely proportional to the number of "sample" trips interviewed as shown below.

Of all trips into and out of zone i there is a certain proportion (p) that will be from or to zone j. Therefore, (p) is the proportion of trip ends in zone i with the other end of the trip in zone j and 1-p (equals q) is the proportion of trip ends in zone i that do not have the other end of the trip in zone j.

If (s) trips with an end in zone i are reported by interview, the probable number ($\bar{X}$) with the other end in zone j is ($s \cdot p$). Mathematically:

$$\bar{X} = sp$$

From any standard statistical text it can also be shown that the standard deviation (σ) of the number of trips reported between zone i and zone j from sample interviews made of trips with one end in zone i is $\sqrt{spq}$. Mathematically: $\sigma = \sqrt{spq}$

The standard deviation (σ) as a proportion of the expected number ($\bar{X}$) is:

$$\frac{\sigma}{\bar{X}} = \frac{\sqrt{spq}}{sp} = \sqrt{\frac{q}{sp}}$$

Since p and q are constants for any pair of zones, the percent error varies inversely with the square root of the number of trips between zone i and zone j obtained by interview.

For 254 zones p will have an average value of $\frac{1}{254}$ and q of $\frac{253}{254}$.

Thus,

$$\frac{\sigma}{\bar{X}} = \sqrt{\frac{\frac{253}{254}}{\frac{s}{254}}} = \sqrt{\frac{253}{s}}$$

Again the average zone had 6,900 trips ends in 1948, of which about 345 were obtained by interview, so on the average s = 345

$$\frac{\sigma}{\bar{X}} = \sqrt{\frac{253}{345}} = .86$$

Thus, for an average movement in 1948 a standard deviation percent error of 86 percent could be expected.

Since the test of forecasting procedures uses the reported 1948 trips as the base data for calculating the 1955 trips and then compares the result with the reported 1955 trips, it would be expected that the error would be increasingly large for the smaller trip volumes, not because of errors in the forecasting procedure but due to sample variability.

The RMS error in the various 1948 volume classes for passenger vehicles in the seventh approximation by the Fratar method behaves in this manner as is shown in table 3 for each of the zone groups.

Table 3.--Percent root-mean-square error by volume class of zone-to-zone movements--passenger vehicles

1948 volume class	254 zones	122 zone groups	66 groups	49 zone groups
20-29 1/	195.0	121.0	95.6	106.1
30-39	222.1	101.4	86.7	83.4
40-49	279.7	118.1	81.5	73.4
50-59	141.0	96.3	82.3	89.4
60-69	139.9	107.5	92.6	89.7
70-79	108.4	74.2	78.2	76.2
80-89	154.3	95.2	94.9	54.4
90-99	128.2	83.0	54.8	73.2
100-199	133.4	93.3	64.8	64.8
200-299	80.5	69.7	58.6	52.1
300-399	60.7	64.0	56.0	43.8
400-499	54.9	56.6	50.9	38.4
500-599	42.6	42.3	45.9	44.1
600-699	51.2	40.6	46.7	48.6
700-799	88.8	41.1	31.1	26.5
800-899	38.9	26.5	57.2	31.6
900-999	18.4	21.4	33.1	38.4
Over-1,000	28.6	27.5	21.2	25.3

1/ Because of home interview sampling ratio of 1:20 in 1948, errors for volume classes below 20 cannot be accurately appraised.

Recommended Procedures

The primary purpose of forecasting zone-to-zone volumes is for the selection and assignment of trips to a transportation network. To do this with reasonable accuracy particularly at each ramp on an expressway network, it is imperative that the zones be of a size consistent with the distance between ramps. Thus, while increasing the size of the zone increases the accuracy of predictions of the zone-to-zone movements, this procedure adversely affects the primary purpose of forecasting. Pending further studies as outlined at the end of this article, it is recommended that zones be established in accordance with present practice and that the zone-to-zone movements be forecast by the Fratar method.

A flow chart for accomplishing this forecast on an electronic computer is shown by figure 7. This chart is made up for an input of zone-to-zone volumes as file A and a combination input of present trip ends, future trip ends and growth factors by zones as alternate inputs for file B. The program includes appropriate editing routines for checking the present trip ends and the growth factors if these are available independently from the zone-to-zone volumes in file A. The switches shown on the flow chart are programed transfer points resulting from decisions made at a remote point in the program. They are not switches on the console of the computer.

A program written from this flow chart includes the computation of the frequency of the new F factors, to be used as a guide for determining the need for continuing additional iterations.

Future Research

The work to date indicates that the three iterative methods are equally accurate in computing the future trips but the Fratar method arrives at the minimum error in fewer approximations. It is also more efficient in its rate of closure.

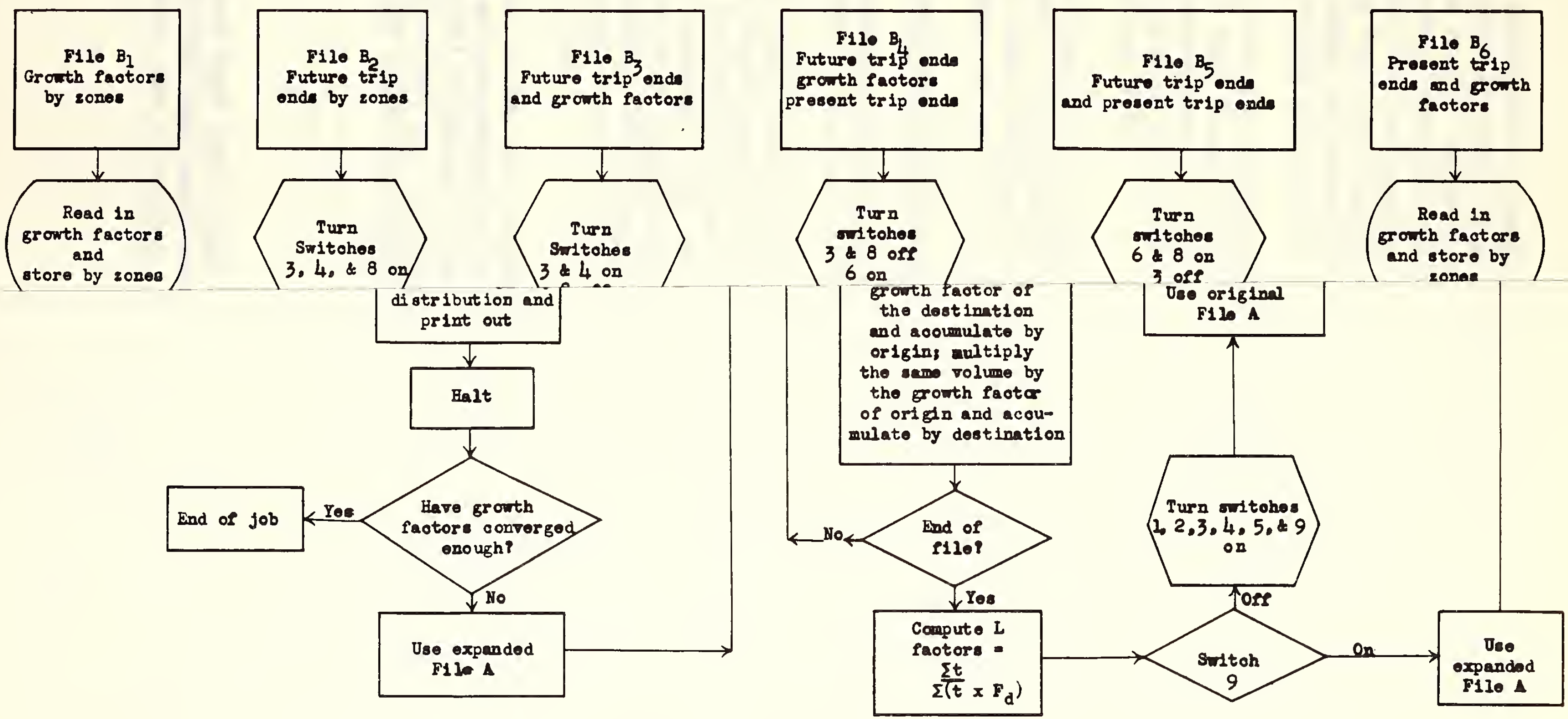
In addition it has been found that the preponderant small volume movements are individually affected by an inherent sample variability. The summation of these movements accounts for a substantial portion of the total trips. It is also known that the small volume zone-to-zone movements are, on the average, the longer trips within the city that account for proportionately more vehicle-miles of travel and are also the trips most likely assignable to high-type highway facilities.

Accumulating trips across a grid

However, it is not necessary that the individual zone-to-zone movements be accurate if a summation of these volumes crossing the city is reasonably representative of the actual travel. To determine this relationship it is proposed that each zone-to-zone movement be traced from the X and Y coordinates of one zone to the X and Y coordinates of the other. Each

FIG. 7

ELECTRONIC COMPUTER FLOW CHART FOR FORECASTING FUTURE ZONE-TO-ZONE TRIPS FRATAR METHOD



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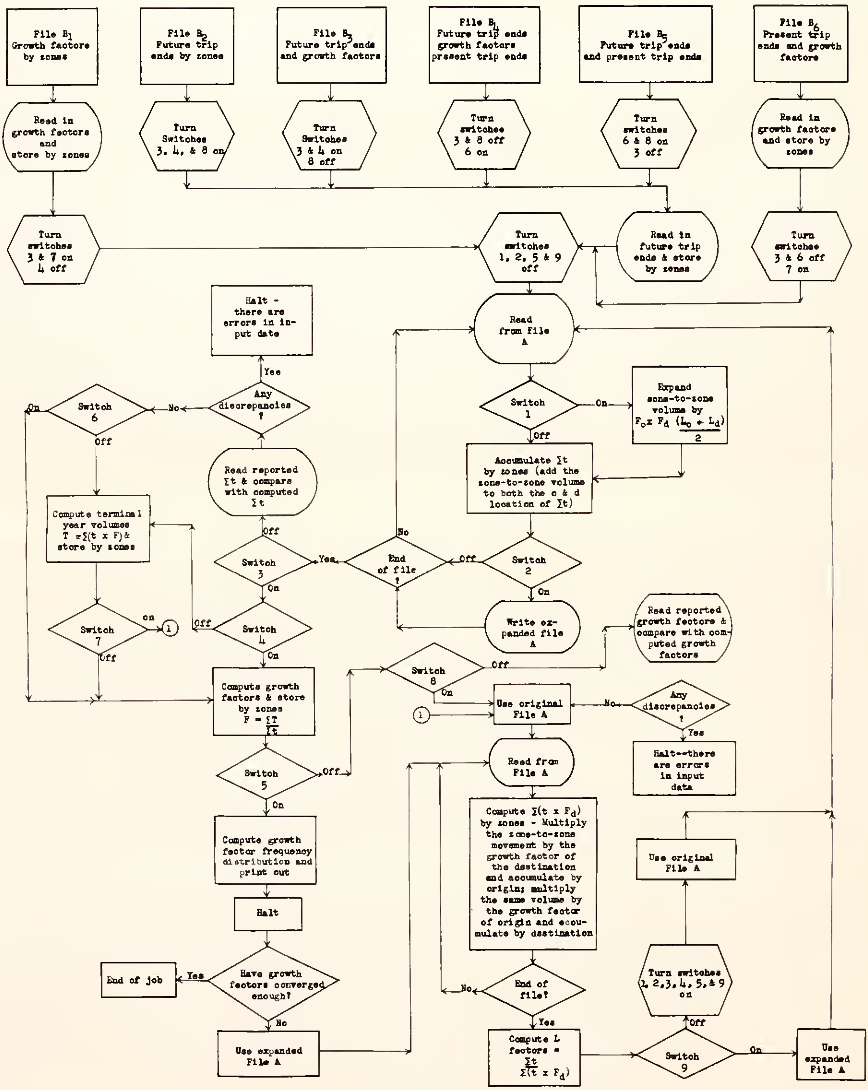
FRATAR METHOD



time this trace intersects a predetermined section of a grid line the number of 1955 trips for this zone-to-zone movement as projected from the 1948 data and the number as determined from the 1955 survey are "remembered." When all zone-to-zone movements have been similarly traced, the number of "remembered" trips over an appropriate interval of each grid line is totaled. The comparison of the total number of trips projected from the 1948 data with the total number determined from the 1955 survey will give a measure of the accuracy of the projection.

The use of the trace principle automatically "weights" the longer trips properly in that longer trips will cross many grid lines whereas the short trips may cross none or only a few. Further, by choosing an appropriate length along each grid line, the summation of trips to various volumes can be accomplished.

While the trace method appears as a difficult manual task it is comparatively simple to program for an electronic computer and would require about the same computer time as a single iteration of the Fratar method if the number of grid lines is held to a reasonable minimum.

Stabilizing the small-volume movements

Another research project which should be undertaken is the testing of methods for stabilizing the small-volume zone-to-zone movements.

One of the more difficult problems in forecasting traffic is that of predicting the future number of trips for the zone-to-zone movements that are zero at the present time since all methods tested require the multiplication of existing trips by various factors. The magnitude of this problem can be most easily visualized by remembering that about 67 percent of all possible 1948 zone-to-zone movements in the Washington, D. C., survey were zero and these same zone-to-zone movements account for 22 percent of all 1955 trips.

In addition to the zero volumes, other low volumes are also inherently inaccurate. For an understanding of this problem it is necessary to again resort to statistical formulae. The proportional error that may be expected in random sampling of all of the trips from one zone to a particular other zone is given by the following expression which has been previously defined:

$$\frac{\sigma}{\bar{X}} = \frac{q}{sp}$$

For example, suppose that zone i has a total of 6,000 trip ends. Of these 6,000 suppose that 666 have their other ends distributed as follows: 600 in zone j, 60 in zone k, and 6 in zone l. With a 1 in 20 sample the 6,000 trip

ends in zone i will represent 300 trip ends obtained by interview; therefore s = 300. Considering all of the trip ends in zone i, the probability of any trip end having the other end in zone j is 600 out of 6,000 or 0.1. Therefore p = 0.1 and q = 1 - p = 0.9. Thus for the trips from zone i to zone j the proportional error = $\sqrt{\frac{q}{sp}} = \sqrt{\frac{0.9}{300 \times 0.1}} = 0.17$. Thus with a one-twentieth sample we could expect a standard deviation accuracy of 17 percent for the trips between zone i and zone j. Similar values for zones k and l are shown in the following table:

Zone-to-zone	Volume	s	p	q	Proportional error	Percent error
i to j	600	300	0.1	0.1	0.17	17
i to k	60	300	.01	.99	.57	57
i to l	6	300	.001	.999	1.83	183

If the sample rate is 1 in 20, it is manifestly impossible that the 6 trips between zone i and zone l will ever be reported as 6 trips. However, from the expansion of the binomial $(p + q)^s$, the frequency distribution of the reported trips between zone i and zone k and between zone i and zone l, is estimated as follows:

Reported number of trips	Probability of reported value-- Zone i - zone k	Zone i - zone l
0	0.05	0.74
20	.15	.22
40	.22	.03
60	.23	.01
80	.17	-
100	.10	-
120	.05	-
140	.02	-
160	.01	-

Thus the 6 trips between zone i and zone l are never correctly reported; 74 percent of the time they are reported as zero; and the remaining 26 percent of the time they are reported as 20 or more trips. Similarly the 60 trips between zone i and zone k are reported as 60 only 23 percent of the time, while the remaining 77 percent of the time the reported trips are in error by more than 33 percent.

Adjacent to zone i there will be other zones i_2 and i_3. To illustrate, it can be assumed that zone i_2 has 8,000 trip ends and zone i_3 has 6,000 trip ends; therefore since zone i has 6,000 trip ends, in zones i, i_2, and i_3 there would be a total of 20,000 trip ends which would represent 1,000 interviews.

Now since zones i_2 and i_3 are adjacent to zone i, it is probably true that their movements to zone 1 are similar in volume to the movements from zone i to 1. This assumption is justified by the high correlation of distance and trip volume as established by Dr. Carroll and others. If this be true we could assume that $\frac{1}{1,000}$ of all trip ends in zone i_2, and i_3 are to or from zone 1 as was the case with zone i, i. e., the 20 trips between zone 1 and the three i zones are divided 30 percent to zone i, 40 percent to zone i_2 and 30 percent to zone i_3. If the expansion process $(p + q)^s$ is again used to obtain the probability of the zone-to-zone movements, the results are shown in the following table:

Reported number of trips to zone 1--

Total	From i	From i_2	From i_3	Probability
0	0	0	0	.37
20	6	8	6	.37
40	12	16	12	.18
60	18	24	18	.06
80	24	32	24	.02

From a comparison of the above table with the previous one it appears that grouping of zones will improve the accuracy of the low-volume movements. This process can be continued for other groupings. However, instead of using this rather time-consuming computation we can obtain the proportional error by the simpler equation $\frac{\sigma}{\bar{X}} = \sqrt{\frac{q}{sp}}$ which does not indicate the frequency of the various movements but does, in one operation, compute the resulting error.

The trips between zones i, i_2, and i_3 combined and zone 1 will have a proportional error of $\frac{\sigma}{\bar{X}} = \sqrt{\frac{.999}{1000 \times .001}} = \sqrt{.999} = 1.00$ or 100 percent. Thus by grouping three zone-to-zone movements the standard-deviation error has been reduced from 186 percent to 100 percent assuming that the distribution of trips between zone 1 and zones i, i_2, and i_3 is proportional to the distribution of trip ends in the three i zones. It is true, of course, that this assumption will not be exactly correct, but it seems likely that the error of this assumption will be less than the error added by the individual zone sample variability.

The problem of how large a grouping is desirable can be approximated from the equation: $\frac{\sigma}{\bar{X}} = \sqrt{\frac{q}{sp}}$. Note that the limiting value of q is 1.00. It can never be as large as 1.00 and in almost all applications it is

not smaller than 0.9. At the same time sp is equal to the number of trips obtained by interview between a pair of zones with perfect sampling. The value of sp can range from zero up to the value of s. The relation between the error of a zone-to-zone movement and the number of interviewed trips making this zone-to-zone movement can be approximated as follows:

Number of interviewed trips	Percent error
0	∞
1	100
2	71
5	45
10	32
15	26
20	22
30	18

Considering the undesirability of combining too many zones, from this table it appears that zone-to-zone movements might well be grouped until the accumulated movement represents about 10 interviews.

A method to accomplish this prupose has been worked out but not tested except by hand computation from a small sample. The sample computation indicated that the error is reduced by approximately one-third.

The method requires the use of the binary system in coding a group of zones. For illustrative purposes we can consider a group of 4 zones although in actual practice probably 16 would be required.

To illustrate, suppose that in region A the area is divided in half with 2 zones in each half. One-half of the zones would be designated A0 and the other half A1. These pairs of zones would again be divided in half or into single zones designated A00, A01, A10, and A11. A separate region B would be similarly separated into B00, B01, B10, and B11.

Now if only trip volumes that represent 10 interviews (or 200 trips with a $\frac{1}{20}$ sample) are considered sufficiently stable so as not to warrant readjustment, a method of combining zones that is amenable to computer operation is required. A suitable method is as follows:

The number of trips from A00 to B00 is examined. If it is less than 200 (10 interviewed trips), combine zone B00 and B01 and find the number of trips between A00 and B00 + B01. If it is still less than 200, combine zone A00 and A01 and find the number of trips between A00 + A01 and B00 + B01. If the number of trips is still less than 200, again double the B area to include 4 zones, and if necessary, double the A area to include 4 zones, and so on until the figure 200 is reached.

The advantage of the binary coding is that it provides the desired grouping through a simple arithmetic operation. The arithmetic operation simply combines the binary portion of the region code by alternate digits. For example, if A00 is written as AA_1A_2, and B00 is written as BB_1B_2 the combination is written $A_1B_1A_2B_2$. Starting with 0000, the digit 1 is added successively until the sum 1111 is obtained. The subtotals are then decoded by the $A_1B_1A_2B_2$ pattern and the zone-to-zone movements are then in the proper order for combining as follows:

Combination	A zone	B zone	Combination-- 1	2	3	4
0000	00	00				
0001	00	01	x			
0010	01	00				
0011	01	01	x	x		
0100	00	10				
0101	00	11	x			
0110	01	10				
0111	01	11	x	x	x	
1000	10	00				
1001	10	01	x			
1010	11	00				
1011	11	01	x	x		
1100	10	10				
1101	10	11	x			
1110	11	10				
1111	11	11	x	x	x	x

From the original zone-to-zone volumes and the combination totals, the preselected volume can be determined.

The combination volume is then reassigned to individual zone-to-zone movements as follows: Suppose that in the previous example all 4 of the A zones were combined and all 4 of the B zones were combined to provide a preselected volume. The total trip ends in the individual zones in the A group are added and the proportion of the total in each A zone is determined (P_{A1}, P_{A2}, etc.). Similarly each zone of the B group is a certain proportion of the B total trip ends (P_{B1}, P_{B2}, etc.). Then the total volume (V) between the group is reassigned to individual zone-to-zone volumes (V_{A1-B1}) by the equation:

$$V_{A1-B1} = V \cdot P_{A1} \cdot P_{B1}$$

$$V_{A1-B2} = V \cdot P_{A1} \cdot P_{B2}$$

etc.

From the sample tests made to date this reassignment procedure appears to improve the accuracy of predicting the future zone-to-zone trip movements. Whether it improves the accuracy of predicting accumulated volumes such as would occur on road sections or ramps should be tested by the process of accumulating the trips across a grid, as described in the preceding section.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Gordon D. Gronberg
Bureau of Public Roads

USE OF ELECTRONIC COMPUTATIONS IN HIGHWAY COST RESEARCH PROBLEMS

Most of the papers given at this meeting have been reports on how electronic computers are being used--ours is only a preliminary report on test runs made to see if research analysis work would be adaptable to electronic computers. And I might say at this time, that it is, in fact to a greater degree than we had thought possible.

Research on highway cost problems has progressed along the path of many other problems in the highway field. First, a problem is defined; then a plan is devised for solving the problem; next the factual data needed for solution are obtained and then comes the computation and analysis work. It is in this last stage--the computation and analysis work--where the slowdown is likely to occur.

Let me give you an example from our highway cost research. About four years ago we uncovered a significant relationship between growth of highway traffic and growth of highway investment. It is one that enables highway needs estimates to be quickly brought up to date and adjusted for changes in traffic from year-to-year. It also enables highway needs to be estimated for long periods of years into the future. True, there are many obscure aspects to the procedures--hence it is easy to appreciate our interest in exploring the problem so as to determine how best to apply it, and to enlarge upon its uses and applications in highway planning.

Accordingly we undertook a series of involved and voluminous computations to check out the procedure. Results found immediate use in current highway needs studies. We were greatly encouraged. There were other results that could have been used, but the ponderous amount of calculations and computations by conventional methods were proving to be a real obstacle to progress on our research work.

Then came the Highway Revenue Act of 1956 which directs certain studies to be made and the results reported to Congress. One of these is the Highway Cost Allocation Study. This is an investigation of an equitable distribution of the tax burden among the various classes of persons using the Federal-aid highways or otherwise deriving benefits from such highways.

We were confronted with the task, in connection with the Highway Cost Allocation Study, of developing the investment or capital outlay in all highways, roads, and streets at today's prices. While the principal emphasis is, of course, on the Federal-aid highway systems, data will also be required for the non-Federal-aid systems. This is necessary in order that matters of equity in Federal taxation can be oriented not only with respect to the needs of the Federal-aid systems of roads and streets but with respect to the needs of all roads and streets. Therefore, the investment will not only be needed for the eight Federal-aid systems, including the Interstate System, but for the four non-Federal-aid systems. This makes twelve in all. We realized that by manual methods it would require weeks or even months to do the job with our present staff or with additional personnel.

Mr. Schureman, Chief of the Bureau of Public Roads' Electronic Branch, was contacted to see whether highway cost computations could be processed on electronic computers. It was decided that much of the manual computation work could readily be applied to a computer program.

As our immediate personnel had no knowledge of the computer programing or operation, we depended on Mr. Schureman for guidance and getting the work started. The over-all problem was carefully studied and divided into four logical component parts or problems. Each problem was considered separately, keeping the over-all picture in mind. Step-by-step procedures were written for each problem. From the step-by-step procedures, electronic computer programs were developed together with block or flow diagrams and printing formats.

I don't want to bore you with a lot of unnecessary details but only to show you the size and scope of our problems.

One problem was to obtain the depreciated investment remaining each year, January 1, 1915 through January 1, 1997. The data will be for five major accounts--grading, structures, and low, intermediate, and hightype surfacing--for the twelve road systems.

1. Interstate, rural
2. Interstate, urban
3. Other FA primary, rural
4. Other FA primary, urban
5. FA secondary rural, State jurisdiction
6. FA secondary urban, State jurisdiction
7. FA secondary rural, local jurisdiction
8. FA secondary urban, local jurisdiction
9. Other State highways, rural
10. Other State highways, urban
11. Other rural roads
12. Other city streets

We estimate over 165,000 manual computations for this problem alone.

Another problem was to determine the construction needs for various future program periods. These construction needs will be developed using the relationship between the growth of highway traffic and growth of highway investment. Construction needs will be developed for any length of program desired.

Electronic computers in plotting stub survivor curves of historical data for mileage and dollars will be used in another one of our problems. Stub survivor curves are the percent of the miles constructed or dollars invested in highways that are remaining in service on January 1 of each year. These stub survivor curves are a graphical picture of what is happening to our highways, or how fast they are wearing out. We expect to make use of the electronic point plotter or data plotter in this problem.

As the Bureau of Public Roads expects to obtain an electronic computer by the end of 1957 or early 1958, our programs are being coded for this machine. These programs are also being designed to enable their use in future years as additional data become available. The input and output card layouts were designed and the programs were machine coded by a mathematician of an outside service bureau. A test run was made on Problem No. 1 on May 26 and the results were 100 percent satisfactory in accuracy and amazingly rapid in computation. The machine time was 6 minutes. By manual methods it would have taken months. When I returned to the office and reported the speed made by the machine the comment was, "Don't do it too fast or we will be out of work". Of course, that will not be the case, but more research work can be undertaken. Problem No. 2 was started about May 23 and a successful test run was made June 3. The machine coding for Problem No. 3 was started about June 14 and the test run was made August 7. Vacations and other jobs on which the mathematician was working delayed the progress of this problem. I give you these dates only to show how fast the work progressed. Problem No. 4 involves percentage computations and plotting of computed data. The step-by-step procedure has been written in the first draft and a tentative block diagram has been made.

The computer is fast and reliable. However, just how does it compare with manual methods in time and savings in dollars? There are many factors and variables to consider to put both methods on a fair and comparable basis. For the computer method the following should be considered: The punching, sorting, and collating of the input data, computation time, punching and listing output data.

In the manual method consideration should be given to the time in making up forms, assembling raw data, posting, computing, checking, and adding results. There are other items that should also be considered, such as frequency of errors, speed and accuracy of operator, size and quantity of data, amount of repetitive computations, unavoidable interruptions and distractions which the high-speed computer would not occasion.

While we have made only test runs so far, we have expanded the information and estimated the time it will take to do the work by electronic computers and by manual methods. In our comparison of the two methods we did not consider all the factors that I previously mentioned as being an influence on the comparison of the two methods. We will take these into account when the final runs are made. We made one comparison using computer time plus listing time versus manual computations, with no checking time included. The machine methods were thirty times faster for Problem 1, fifteen times faster for Problem 2, and 120 times faster for Problem 3. For all three problems combined the machine methods were fifty-five times faster. We made another comparison using computer time plus listing time versus manual computations, including checking time. When checking time was included, we found even greater ratios. The average of all three problems was increased from fifty-five times faster to ninety-five times faster.

We, of course, like everyone else, are interested in the savings in costs. However, our main interest was the speed in which these problems could be accomplished as it would be impossible to complete the work manually in time to be used in our analysis work. We found that to do the work manually for all three problems, including checking time, would cost us nearly four times as much.

The present computer program is tailored largely to meet our analysis needs for the Highway Cost Allocation Study. Later we plan on adapting it to the type of problems encountered by the individual States. Here, we see great opportunities in opening up the entire area of road life and road cost research to useful exploitation by the individual States. Results will find immediate use in economic justification studies, highway needs studies, and highway finance and cost allocation studies at both State and national levels.

We are well pleased with the results obtained so far. The procedure has been proved out and we are on the verge of reaping the benefits. We have made a major break-through in what was heretofore an almost insurmountable workload.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Paul E. Irick
AASHO Road Test

THE USE OF HIGH-SPEED DIGITAL COMPUTERS IN ANALYZING EXPERIMENTAL DATA

In this brief discussion we shall raise four questions and attempt to give some answers for each question. If our remarks are to have general application, then we must adopt some pretty general views on the nature of experimental research and on the nature of mathematical analysis for experimental data. Tables A and B have been prepared to show some of these generalities.

The first question is raised at the right end of Table A, "What are pertinent criteria for the use of high-speed digital computers when analyzing experimental data?" We must suppose that this question refers to mathematical analysis, for a digital computer requires a mathematical problem. If we were to read a tapeful of well-identified experimental data into a high-speed computer along with the command "See what you make of that!", we should only expect the computer to stare back at us. On the other hand, if the same data and command were given to a research worker in the field represented by the data, we might get back some pretty good answers without benefit of mathematical analysis. Every experimenter makes use of subjective methods of analysis but a computer cannot do so.

Let us assume that a clear mathematical problem has been found for the computer, that the algebra of the solution is clear and consistent with the problem, and that the arithmetic has been efficiently and correctly programed for the computer. We still must ask whether the problem is consistent with the data and with the experimental setup which generated the data. An experiment has design elements which lead to data acquisition and analytical elements which are necessary to the analysis. There is not time to go into the nature of these elements which represent the structure of the experiment, but we must ask whether these elements are clear and consistent with one another. Moreover, we should try to determine the extent to which the experiment is consistent with the objectives of the investigation.

It is our point of view that there should be a reasonable degree of clearness and consistency for the whole investigation--from objectives on through analysis--if we are to contemplate the use of high-speed computers for analyzing experimental data. If the clearness-consistency chain breaks down somewhere, then the computer's solution may only be of academic interest, and perhaps no analysis at all should be attempted.

In addition to clearness and consistency criteria we must include time and cost criteria. The latter criteria are practically automatic, although when comparing high-speed computer time and cost with time and cost of man-desk computer analysis, we must remember to amortize data preparation and programing costs for both methods of computation.

In answer to our first question, we have implied that clearness and consistency criteria are not trivial, and that these may well be the most important criteria for the use of high-speed computers in analyzing experimental data.

The second question we shall ask is, "What is a mathematical analysis of experimental data?" Our answer is suggested in Table B. Although Table B may not be completely general, we feel that it applies to a great majority of experimental investigations.

We may suppose that the experiment results in M observations, and that with each observation are associated values for independent variable X_1, X_2, etc., and a value for a dependent variable Y. Values for the independent variables may be set by design or determined by measurement, and values for the dependent variable represent one or more response phenomena in the experimental setup.

By definition an experiment is a trial, or set of trials, and it must always be supposed that somewhat different values would arise for the dependent variable if the experiment were conducted in a different spatial or time order. That is, we must suppose that there are unmeasured variable in the experimental enviornment which may affect the data. Indications of the effects of unmeasured variables must come from an identification of the observations with layout variables, i.e., variables which show space and time positions of the observations. These layout variables, denoted by L_1, L_2, etc., in Table B, then become indexes for measuring experimental error (the net effects of unmeasured variables).

Now the general mathematical problem is to express the dependent variable Y as a function of the independent variables X_1, X_2, etc. This function will contain parameters P_1, P_2, etc., which relate to the whole universe of possible experiments and not just to the particular trial (experiment) that was performed.

In order to have a specific mathematical problem we must assume or hypothesize some mathematical model, or formula, for Y which accounts for all variables and parameters in the universe of experiments that might have been performed. As is indicated at the lower left of Table B, this model may call for new variables to replace the experimental variables. For example, the model might replace Y by $Z = \log Y$, X_1 by $V_1 = X_1^2$, etc. The effects of unmeasured variables may be represented by error terms E_1, E_2, etc., and the original parameters may be characterized by coefficients

A_1, A_2, etc. If we assume r coefficients for the mathematical model, $A_1, A_2, \ldots A_r$, and s error terms, $E_1, E_2, \ldots E_s$, then the mathematical model might be of the form $Z = A_1V_1 + A_2V_2 + \ldots + A_rV_r + E_1 + E_2 + \ldots + E_s$ as is shown on the right side of Table B. Not only must the mathematical model be assumed, but assumptions must be made on the probability distributions of the experimental errors $E_1, E_2, \ldots, E_s$.

Under these conditions we have a specific mathematical problem--to estimate the coefficients $A_1, A_2, \ldots, A_r$ and to obtain probability factors which show the degree of certainty with which the coefficients have been estimated.

To summarize, a mathematical analysis of experimental data has been defined as a transformation of experimental data to probability estimates of coefficients for a mathematical model.

The third question for our discussion is immediate--"What algebraic and arithmetic computations are necessary in the mathematical analysis of experimental data?" First, it is necessary to solve r simultaneous equations in order to arrive at the estimates $a_1, a_2, \ldots, a_r$. This may represent the main effort in the computer program. Since there are M observations, we may say that there are M degrees of freedom for the experimental data. Since r degrees of freedom were used in solving r simultaneous equations, there are M-r degrees of freedom left to estimate the effects of unmeasured variables. The second part of the mathematical analysis consists in estimating error effects so that the previous estimates of coefficients may be appraised for their significance and reliability.

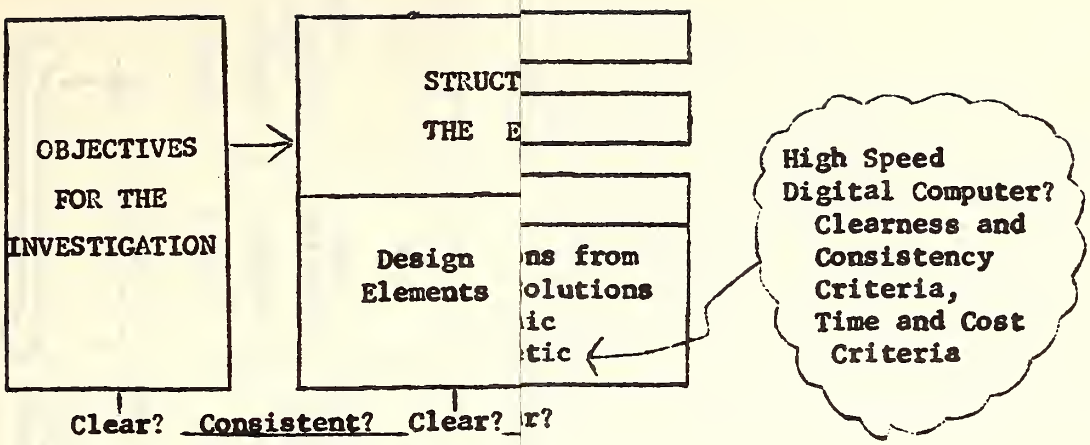
Thus the mathematical analysis ends with an equation, $\hat{Z} = a_1V_1 + a_2V_2 + \ldots + a_rV_r$, and with probability factors for each estimated coefficient and for the equation as a whole. From a graphical standpoint we may say that the analysis ends with curves to represent the order that exists among the experimental variables, and measures of scatter to represent the disorder that exists because of unmeasured variables.

Our fourth and last question is, "What is the nature of high-speed digital computer analysis for experimental data from the AASHO Road Test?"

Table C shows the geographical layout of the Road Test and lists most of the independent variables which are controlled in the experiment. Nearly all other independent variables in the Road Test are specified to remain constant except for climatic conditions.

There will be many dependent variables in the Road Test to represent the response of pavements and bridges to traffic and climatic variables. The dependent variables will include subsurface conditions, deflections under static and dynamic loads, measures of accumulated deformation and deterioration, and perhaps indexes to represent the overall condition of pavements and structures. We do not have time to examine details for the corresponding analyses, but for each dependent variable, the criteria of clearness,

consistency, time and cost are being applied. Wherever these criteria indicate the suitability of high-speed computer analysis, programs are being written for the Datatron computer in order to solve the necessary simultaneous equations and to obtain reliability measures for the output equations. These output equations will then show the significant associations among the dependent and independent variables in the AASHO Road Test.



EXPERI-MENTAL DATA	Obser-vation	Independent Variables X_1 X_2 ...	of X_1, X_2, ... having parameters rimental universe
	1 2 : M	Values determi by design and by measuremen	e.g., + $E_1 + E_2 + \ldots + E_s$, A_r or E_1, E_2, ..., E_s
DATA FOR THE MATHE-MATICAL MODEL	Obser-vation	Regression Variables V_1 V_2 ... V_r	..., a_r for A_1, A_2, ..., A_r
	1 2 : M	X_3, X_2, ... or transformatio of X_1, X_2, ..	$-E_1-E_2-\ldots-E_s$ obtain a_1, a_2, ..., a_r nate distributions of E_1, ..., E_s ability limits for $a_1,\ldots,a_r$ and $\hat{Z}$
Degrees of Freedom		r	

consistency, time and cost are being applied. Wherever these criteria indicate the suitability of high-speed computer analysis, programs are being written for the Datatron computer in order to solve the necessary simultaneous equations and to obtain reliability measures for the output equations. These output equations will then show the significant associations among the dependent and independent variables in the AASHO Road Test.

TABLE A: SCHEMATA FOR EXPERIMENTAL RESEARCH

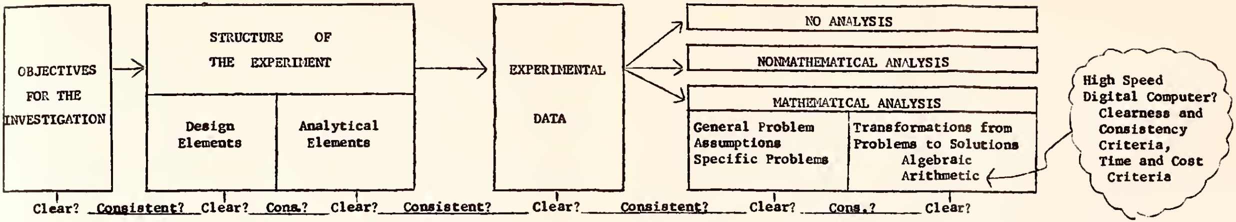


TABLE B: SCHEMATA FOR MATHEMATICAL ANALYSIS OF EXPERIMENTAL DATA

	Obser-vation	Independent Variables X_1 X_2 ...	Layout Variables L_1 L_2 ...	Dependent Variable Y
EXPERIMENTAL DATA	1, 2, ..., M	Values determined by design and by measurement	Values associated with the space-time layout of the experiment	Values to represent response phenomena
	Obser-vation	Regression Variables V_1 V_2 ... V_r	Error Identification E_1 E_2 ... E_s	Variable of Analysis Z
DATA FOR THE MATHEMATICAL MODEL	1, 2, ..., M	X_3, X_2, ... or transformations of X_1, X_2, ...	Deviations identified with net effects of unmeasured variables in the experimental environment	Y or some transformation of Y
Degrees of Freedom		r	M-r	M

General Problem: Express Y as a function of X_1, X_2, ... having parameters P_1, P_2, ... in the experimental universe

Regression Problem:

Assume a mathematical model for Z, e.g.,

$$Z = A_1V_1 + A_2V_2 + \ldots + A_rV_r + E_1 + E_2 + \ldots + E_s$$

with parameters A_1, A_2, ..., A_r

Assume probability distributions for E_1, E_2, ..., E_s

Find probability estimates a_1, a_2, ..., a_r for A_1, A_2, ..., A_r

$\hat{Z}$ for $Z - E_1 - E_2 - \ldots - E_s$

Transformations:

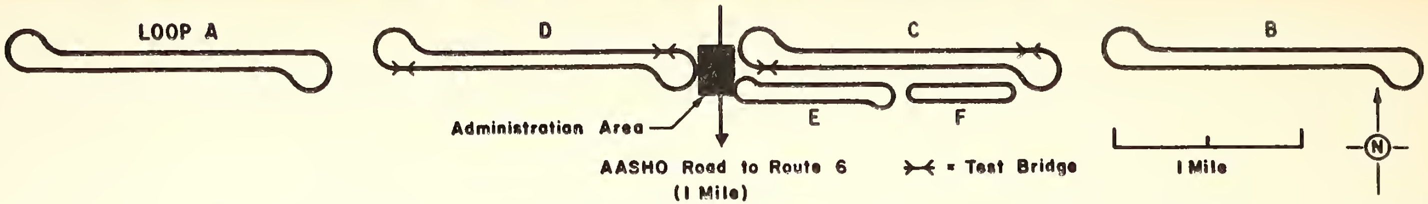
Solve r simultaneous equations to obtain a_1, a_2, ..., a_r

Use M-r degrees of freedom to estimate distributions of E_1, ..., E_s

Solution: $\hat{Z} = a_1V_1 + a_2V_2 + \ldots + a_rV_r$ with probability limits for $a_1, \ldots, a_r$ and $\hat{Z}$

TABLE C.

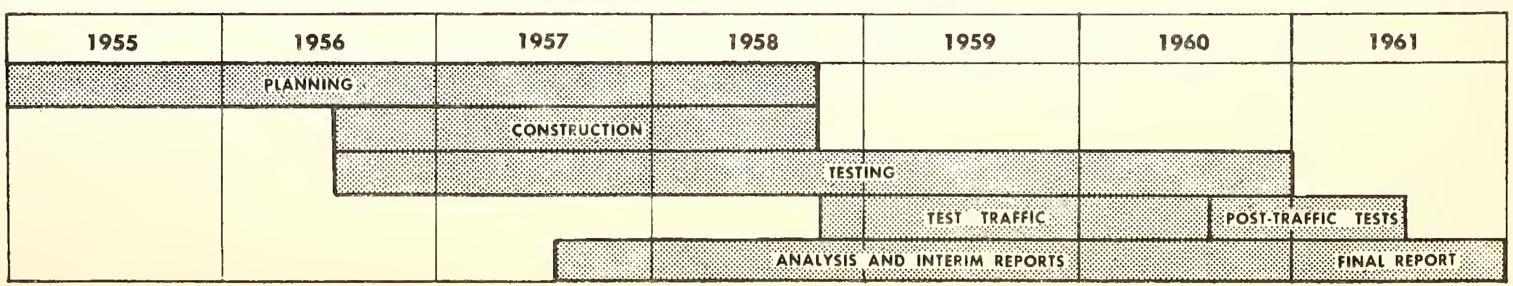
LAYOUT OF THE AASHO ROAD TEST



	LOOP A	LOOP D	LOOP C	LOOP E	LOOP F	LOOP B
Test axle loadings:	12,000-lb. single 24,000-lb. tandem	30,000-lb. single 48,000-lb. tandem	22,400-lb. single 40,000-lb. tandem	2,000-lb. single 6,000-lb single	No traffic Strain test traffic	18,000-lb. single 32,000-lb. tandem
Rigid Pavement:						
No. of test sections	68	68	68	40	56	68
Concrete slab thicknesses	3.5, 5.0, 6.5, 8.0	8.0, 9.5, 11.0, 12.5	6.5, 8.0, 9.5, 11.0	2.5, 3.5, 5.0	2.5, 5.0, 9.5, 12.5	5.0, 6.5, 8.0, 9.5
Subbase thicknesses	0, 3, 6, 9	0, 3, 6, 9	0, 3, 6, 9	0, 3, 6	0, 6	0, 3, 6, 9
Flexible Pavements:						
No. of test sections	84	84	84	68	64	84
Asphalt Concrete Surfacing thicknesses	2, 3, 4	4, 5, 6	3, 4, 5	0*, 1, 2, 3	1, 3, 5	3, 4, 5
Base thicknesses	0, 3, 6	3, 6, 9	3, 6, 9	0, 3, 6	0, 6	0, 3, 6
Subbase thicknesses	0, 4, 8	8, 12, 16	4, 8, 12	0, 4	0, 8, 16	4, 8, 12

Notes: Special sections to study effects of paved shoulders, base type, etc., are not shown here. *Surface treatment.

PROJECT SCHEDULE



Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Discussion on

The Organization of a Computer Division and Its Place

in the Highway Engineering Organization

Moderator

S. E. Ridge--U. S. Bureau of Public Roads

Theodore F. Morf--Illinois Division of Highways

Robert J. Hansen--Washington Department of Highways

Sam Osofsky--California Division of Highways

Ben W. Steele--Oklahoma Department of Highways

S. E. Ridge
Bureau of Public Roads

The subject of this discussion is to me very important. As in other fields of endeavor, organization is important to the success of our efforts in electronic computation. The most delicate balance must be maintained between the authority of the computation group, which is in effect a service group to the other parts of the highway organization, and the other major components of the organization. The computer segment must have enough authority to be able to move ahead in the development of the use of computation without undue restraint by the other offices but, at the same time, the other offices, who are actually responsible for the results of the engineering work, must have the authority necessary to the carrying out of that responsibility.

The whole idea of a centralized computation service is new. And anything new requires some change; some giving on the part of the older segments of the organization. On the other hand, this new organization cannot be too dogmatic in its approach to the problem. It also must give a little even if some of this giving is only for the sake of assuaging certain ideas which are somewhat in the nature of prejudices. No idea, no matter how good or how economic it is, is of any practical value until it is put to some practical use. With this short sketch of the subject, I think we should hear how the problem has been attacked in at least four different areas of the country.

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Theodore F. Morf
Engineer of Research and Planning
Illinois Division of Highways

ORGANIZATION OF A COMPUTER DIVISION AND ITS PLACE IN A HIGHWAY ENGINEERING ORGANIZATION

This matter is one which falls within the field of the student of public administration. One of the more eminent authorities on public administration has said that there are four ways to divide work in an organization and he has referred to these as the four "P's."

By PURPOSE - that is a functional classification of work and in the field of highways we might consider that construction, design, and maintenance are functional entities.

By PROCESS - that is according to skills and disciplines such as legal, medical, engineering, statistical, accounting, etc.

By PLACE - that is according to geographical boundaries. Here we might consider whether a unit of work is to be carried on in a central agency on a statewide basis, or whether it is to be performed in districts, divisions or regions, separately.

By PEOPLE - that is by clientele. Are we concerned with children, or veterans, or tuberculars, etc? Since engineers are mainly concerned with things rather than with people, this classification has only slight relevance to our work.

To these four "P's" I might add a fifth P.

By POSSESSION - By possessing a certain group of equipment the materials testing agencies in many highway departments have also assumed physical research functions. By possessing standard EAM equipment the statistical or accounting agencies in many highway departments are entering the field of electronic computing.

Each of these four P's, (and this group might indulge me by permitting the addition of the fifth P) are good sound and justifiable basis for organization and do indeed provide the rationale for much of our present overall highway structure.

We have two electronic computer units within the Illinois Division of Highways. A rather small unit within the Bureau of Research and Planning, and a much more complete unit in the Chicago Area Transportation Study.

It is the mission of the smaller unit to develop programs suitable for use in our highway work and to turn out production work after those programs are developed. This unit is headed by a top-flight highway design engineer who also lays out the flow diagrams and the mathematical equations involved. We have a plan under which structural designers are loaned to this unit to assist in the preparation of structural problem programs.

Under the head of this unit we have a mathematician who codes the problems in the language of the particular machine we are using. Also under him is the computer operator and data preparation typists. We believe that a first-class engineer needs to be associated with the computer unit to interpret data received from the district field offices or from bridge designers and to inspect and evaluate the results of the computation process.

The size of this unit is quite small because we are expecting to avail ourselves of people in the larger CATS unit when the initial surge of work in that agency has passed.

The computer unit of the CATS is closely associated with the regular EAM installation through which the original field data were put on a tabulating card record and brought into rough shape. This organization is concerned principally with data processing as distinguished from engineering or scientific computations. Aside from supervisory personnel and EAM perators there are six computer programers in this unit each of whom is capable of operating the computer to debug his own program.

One of the questions which has arisen in this unit is the extent to which computer programers should also be computer operators. Certainly for debugging or testing out programs it is simpler for the programer to try it on the machine himself than to explain its complications to another operator specialist. On the other hand, being less familiar with all the details of the operation of the machine, the programer may make errors in operation which will delay the checkout of his program. Furthermore, there is a rather expensive tendency to use the machine to find the program errors which might have been more cheaply detected by a rigorous check of the coding work.

As the main processing of the data assembled by the CATS is completed, we are planning to redivide the workload between the two computer units to fit the relative capacities of the equipment and the availability of personnel.

There is not too much in these remarks to establish absolute requirements in organization. However, it is clear that a computing unit will necessarily be in a separate organization from the designers or construction people who are its customers. To be useful, there must be mutual respect, confidence, and understanding. For this reason we believe that the computing unit should be headed by an engineer of unquestioned ability and knowledge of the fields in which the computations are to be used. We believe that it is much easier to give a good engineer competent training in computer techniques than it is to give a good programer competent training in engineering practices.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Robert J. Hansen, Supervising Highway Engineer
Washington Department of Highways

A COMPUTER DIVISION AND ITS PLACE IN THE HIGHWAY DEPARTMENT

We have all been led to believe at one time or another that the potential of a computer is unlimited. However, I am inclined to disagree with the statement, as the potential varies in direct proportion to the Computer Division organization and the capabilities of its personnel.

A Computer Division is a relatively new organization in many highway departments. In fact, so new that its functions and duties have never been clearly defined. Of course, its purpose is to save engineering man-hours. But how should an organization be set up to develop, process, and promote the uses of this engineering tool in the most effective manner to provide maximum results?

About a year ago, I was given the job of organizing a Computer Division in the highway department. Fortunately, we have as Director of Highways, Mr. W. A. Bugge, who has a thorough and complete working knowledge of organizational principles. At that time he made some very important decisions to be used as a guide for the logical and methodical formation of a Computer Division.

The basic principles of organization that Mr. Bugge used included the following:

1. Set up distinct lines of authority.

2. Locate the division in the most logical grouping of activities.

3. Insure the division of control and coordination necessary for an efficient and effective organization.

4. Place definite responsibility on the engineer in charge.

Thus from the above principles the Computer Division was located under the Office Engineer who is directly responsible to the Director. Other units under the Office Engineer include the Accounting Division, Public Relations and Permits Division. In this position, the Computer Division conducts its work with other divisions on much the same level and directness as the Accounting Division.

The amount, variety, and complexities of computer application was also considered in the organization and placement of the Computer Division. The division can and will in the future perform services for every other division in the department and oftentimes will work directly with the engineer. As an example of the broad scope of its services the Computer Division in the State of Washington presently serves the various divisions of the department with the following list of applications:

A. BRIDGE DIVISION AND TOLL BRIDGE AUTHORITY

1. Moment Distribution of Continuous Spans
2. Dead Load Deflection Calculations
3. Beam Characteristics
4. I-Beam Section Properties
5. T-Beam Analysis
6. Hydraulic Backwater Curve Computations
7. Computation of Influence Lines
8. Skewed Bridge Calculations
9. Calculations of Slopes and Deflections of Finite Beams
10. Calculation of Moments in Finite Beams
11. Matrix Program to Solve Simultaneous Equations
12. Traverse Computation for Bridge Layout

B. PLANNING AND TRAFFIC DIVISION

1. Forecasting Zonal Traffic Volumes
2. Speed Check Analysis
3. Polynomials of Best Fit by the Least Squares Method

C. MATERIALS LABORATORY

1. Calculation of Maximum Density Curves
2. Swedish Slip-Circle Analysis of Soil Stability

D. PLANS AND CONTRACTS DIVISION

1. Low Bid Analysis of Project Lettings

2. Cost Index Computations

E. ACCOUNTING DIVISION

1. Payroll

F. PERMITS DIVISION

1. Overweight Permit Fee Study

G. DISTRICT FIELD ENGINEERS

1. Earthwork Computations

2. Design Template Note Computations

3. Lateral Shifting of Cross-Section Notes

4. Traverse

The above list is only in its infancy, in addition to the above programs that have been made available to the department, we have a list of approximately thirty (30) other known problems that should be developed for the computer in the near future.

Another factor in the success of a Computer Division is the determination of personnel needs for an adequate staff. It was realized that the writing of a program requires a few days for simpler problems to months where the problem is complex. Weighing the programing time against the number of unsolved problems, we arrived at the need for five (5) programers. It must be remembered that an adequate number of programers is also economically necessary both for maximum machine usage and man-hours saved.

On the following page is a very simple organizational chart of our Computer Division. You will note that the programers are made up of a Bridge Engineer, three Highway Engineers, and a mathmatician. One of the highway engineers has had eleven years of I.B.M. experience. The Senior Highway Engineer as shown is a Bridge Engineer and I am a Planning and Traffic Engineer.

The question probably has arisen in each State as to whether it is better to teach an engineer how to program or to have a programer learn something about the engineer's problem. We have utilized both the engineer and

trained programers as a method of introducing the computer to the department. Engineering personnel from each division have attended a two weeks' course on computers. To date, three very useful programs have been written by engineers outside of the Computer Division.

We have not discouraged the writing of programs by engineers in other divisions. However, we believe that the preparation of a program is a highly specialized field and should be accomplished within the Computer Division by personnel having a complete understanding of the capabilities and limitations of the equipment.

The discouragement of program writing outside of the division usually arises from high priority engineering problems and the normal day-to-day duties of the engineer.

Concerning the functions of a well-organized Computer Division, I have prepared a list as follows:

1. To develop electronic computer applications under the direction and cooperation of other divisions of the department.

2. To prepare data processing instructions for the engineer and provide the proper forms for the submission of data.

3. To investigate and make available computer programs developed by other States and agencies.

4. To process data in accordance with written instructions and present the results in the most effective and logical form.

5. To maintain adequate and uniform files for use in providing tabulated data for final records.

6. To aid in research programs and studies and make recommendations and/or suggestions concerning use of machine methods.

7. To promote the use of the electronic computer by informal classes and instruction and the dissemination of informative material to potential users of the department.

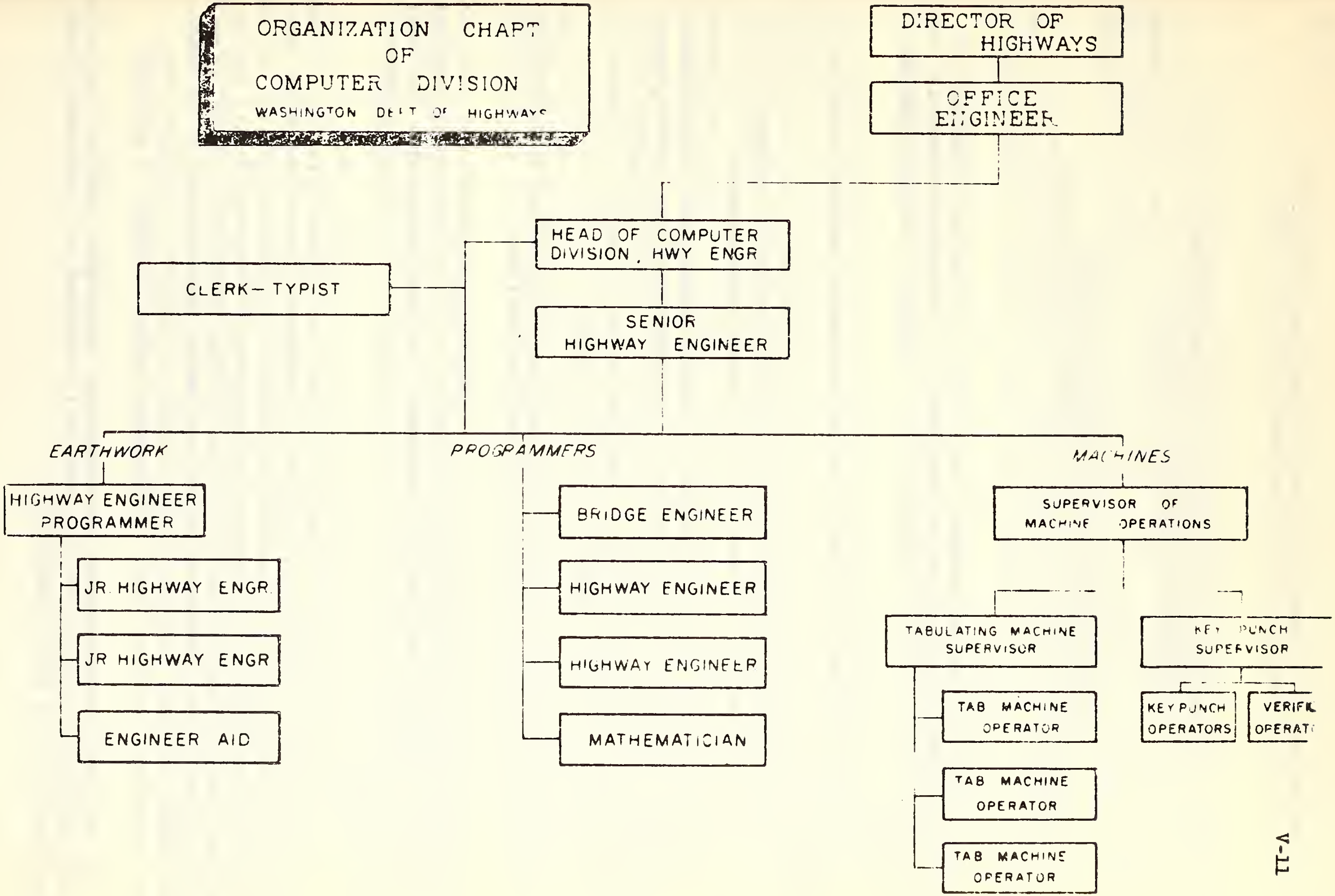
8. To maintain adequate records of machine operating procedures.

In our day-to-day processing and development we have established a guide that no engineering decisions should be made in the Computer Division. Only by keeping the operations as mechanical as possible can we achieve maximum efficiency of both personnel and machines. Of course, a great amount of engineering is used in the review of output and input data and for the development of programs. But the decisions as to method, equations, significant figures, constants, etc., are decided upon by the engineer who has requested the problem to be solved on the computer.

The same is true for our earthwork processing. We try to limit our work to the mechanical phase since the engineer has more time available for engineering when utilizing electronic computers.

Again I would like to re-emphasize the importance of the organization of a Computer Division and its personnel. There is a potential saving of hundreds of thousands of dollars in each and every highway department in the country and thousands of engineers are waiting for the opportunity to do more engineering. The responsibility of realizing these potentials rests clearly on the organizational structure of a Computer Division, its place in the department, and the personnel assigned the task of attacking this enormous undertaking.

ORGANIZATION CHART
OF
COMPUTER DIVISION
WASHINGTON DEPT OF HIGHWAYS



Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts, September 17-18-19, 1957

Sam Osofsky, Supervising Highway Statistician
California Division of Highways

THE ORGANIZATION OF A COMPUTER DIVISION AND ITS PLACE IN THE HIGHWAY ENGINEERING ORGANIZATION

The dictionary defines computer by referring to the work "calculate" which indicates that computing is the performance of a simple arithmetic process, but in highway work we certainly would not admit the computing we do is simple.

I found an acceptable definition of an electronic computer which is as follows:

> "An electronic computer is a very fast calculating machine with the ability to memorize numbers and instructions."

Please note that there is nothing in the definition that infers that the computer has the ability to think or that it has a brain. In fact, some of the recent literature on electronic computers has taken great pains to assure the reader that the electronic computer is not a "brain". I personally like to call the electronic computer a "rapid moron".

Since the electronic computer does not have a brain, the organizational setup will have to provide personnel with thinking ability.

There are conflicting ideas as to the desirable organizational setup in highway engineering. One group believes that it should be made up of engineers--not only just engineers, but the best engineers that are available. The other group believes that the top man should be an engineer with trained programers working for him.

In my opinion it is not imperative to have an engineer directly in charge of the installation. The prime requisite is someone capable of assuming that level of responsibility. Engineers can be detailed to work on specific problems at which they are expert. (No one can be expected to be expert in all fields of highway engineering--highway design, bridge design, construction, right-of-way engineering, etc.) On completion of the programing these men may be released. We have found that more than one expert should be consulted to assure that current variations are considered and included in the program, if possible.

It has been our experience that there are few highly competent engineers who would appreciate or enjoy being permanently attached to a programing unit and lose contact with their specialty.

In other engineering fields occasionally an "open shop" arrangement is maintained. The engineer can be trained in a relatively few hours to write his program for a one-time problem in an interpretive system and, in many cases, to actually run the program on the computer. (The use of an interpretive system saves programing time at a sacrifice of machine time.)

To warrant an installation of a computer other than engineering, computations may be necessary. Usually the non-engineering data processed is for accounting functions and/or the processing of planning survey data.

In the past we have processed maintenance and construction costs, road life, accidents, origin and destination studies, road inventory, status of highway programing, traffic analysis, bridge statistics, etc.

These functions do not require a medium sized computer, they are primarily in the data processing field. I consider that the "bread and butter" jobs in highway engineering are also in the data processing field. For example, in California, for earthwork, we are processing approximately 300,000 cards per month, averaging over 200 miles per month. In traverse we are now averaging better than 3,000 courses per working day. Since the process for each is so complicated and since in each procedure there is a large amount of computing involved, a considerable saving in time and increased accuracy is obtained by the use of a data processing machine of the 650 class.

In California, because of our work load, we have to resist the temptation to process data on the IBM 650 that can be done more economically on conventional equipment. We have therefore, continued to keep an IBM 604 calculator in our installation.

Prior to obtaining the 650, traverse and earthwork were processed on a 604. We are now using the 604 for the following engineering computations in addition to using it for accounting and planning survey data processing functions:

We have developed computing services which we call:

1. Four-factor computation service.

   It is used to compute and summarize quantities for retaining walls, abutments, bent footings, structural quantities, etc. It has been suggested as a possible method for the following:

   (a) Weight scale quantities

   (b) Preparing excavation slopes (erosion control)

(c) Preparing roadside areas (roadside development)

(d) Clearing and Grubbing

(e) Areas for select rock protection

(f) Mixing, spreading and compacting (cement treated base and cement treated sub-grade)

This program will perform any of the following four types of computations involving four factors of six digits, and will maintain two-decimal accuracy. Mathematically, the combinations fall into these categories:

(1) A.B.C.D.

(2) $(A \neq B) \cdot (C \neq D)$

(3) $(A \neq B \neq C) \cdot D$

(4) $(A \neq B)\ C \cdot D$

In addition to making the above computations showing the individual calculated results, the results are summarized showing three classes of totals or two classes and the summation of factors A and B. This ability to summarize or accumulate algebraically the individual calculations provides considerable flexibility and makes it possible to handle a large variety of mathematical computations.

2. Reinforcing steel quantities.

The machine computation service computes and summates quantities of reinforcing steel by bar size. Standard bar sizes No. 3 to 18 are handled automatically. If other standard bars are developed they can be added.

3. Point on curve and central angle computations.

The input is as follows:

(a) Station of beginning of curve

(b) Station of point on curve (can be either input or one of the unknowns)

(c) Radius of the curve

(d) Bearing from beginning of curve to radial point

(e) Bearing from radial point to point on curve (or an unknown)

The output is as follows:

(a) The arc distance between point on curve and beginning station

(b) Central angle in degrees, minutes, and seconds between point on curve and beginning station

(c) A copy of the input is also included

Samples of input data and tabulated results are shown for 604 applications to engineering as an appendix.

In addition to the above, until we revise our earthwork program, we are handling line shifts and grade changes on the 604 prior to feeding the cards through the 650.

For an organization processing the volume handled by California, it becomes necessary to have in the organization personnel who are specialists.

We are trying to build up a unit within our organization wherein the personnel will have the title of Scientific Programer. This group will be almost entirely occupied with programing problems in engineering for the Magnetic Drum Data Processing Machine. It will work closely with the engineer who is expert in a particular field.

Also needed are personnel expert in programing the computer with knowledge in accounting and in statistics.

Another group will handle the procedure writing on the conventional equipment used before and after the computer phases or for other than engineering functions.

In California, we have used research and statistical personnel for the procedure writing involved in accounting and statistics with a small group trained to handle the programing on the IBM 650. People with tabulating ratings are used for the actual operation of the equipment. If the volume warrants, the procedure writing on accounting functions can also be handled by personnel with tabulating ratings.

There has also been considerable controversy as to the feasibility of centralizing a computer organization. We believe that this has been worked out successfully in California.

Whether the installation is in the building or not, the use of a computer must be scheduled; it cannot be used as a desk calculator. A waiting period for the engineer is unavoidable. The engineer must reschedule his work to allow for this waiting period between submittal of a problem and receipt of the results. With a little education this has been found quite feasible.

We do not expect from our Districts 100 percent of the computations possible for each of the services we are making available. In many cases the engineer, by performing a few calculations, can make it possible to send into Headquarters a larger volume at one time and thereby reduce the elapsed time of the over-all job.

The type of equipment needed in the highway engineering organization should be determined by individual studies and the answer depends to a great extent on the type of computer and on the work load for this computer. For most State highway departments, if a medium size computer (of the same class as the IBM 650 Magnetic Drum Data Processing Machine) is included in the installation an additional computer such as an IBM 602A, 604, 607 or a Univac 120 will probably not be needed, since the medium size computer can do everything that the smaller computers can accomplish, and if the work load permits, it might just as well be used.

The type and number of auxilliary equipment needed in addition to computers depends to a great extent on the type of work and work load undertaken. From our experience, consideration should be given to the large number of one-time jobs that do occur. The equipment should provide the flexibility needed to handle that type of an operation. The number of each type of equipment should provide enough cushion to handle an additional work load. It is not necessary to provide warrants for the equipment, nor is it possible, normally, to keep each piece of equipment busy a full eight hours every day. Where available, consideration should be given to the type of equipment that will handle both numeric and alphabetic information.

The computer division should act as a service bureau for all sections of a highway engineering organization.

In order for the computer division to function properly it should include personnel with backgrounds in mathematics, statistics, and accounting and have engineers available for consultation.

With the type of organization suggested it should be possible for a highway engineering organization to make use of new mathematical and statistical tools, such as sampling, quality control and linear programing.

In closing, let me emphasize that when organizing a computer division in a highway organization our thinking should be geared to an electronic data processing machine which is only incidentally a computer and that its function is not to be thought of in the same manner as the desk calculator found on most of our desks.

6-442.1 PREPARATION OF DATA SHEET The machine computation service extends and summates quantities of reinforcing steel by bar size. Data shall be submitted on Form BD-34 Rev. in the prescribed manner as shown in Figure 6-442.1. In general, the instructions for submitting traverse data given under Index No. 6-412.2 shall apply to computations for reinforcing steel quantities. Following is a listing of the corresponding subparagraphs given under Index No. 6-412.2 with appropriate changes noted.

(1) Problem Number Does not apply.

(2) District Number No change.

(3) Group Letter No change.

(4) Batch Number No change.

(5) Transmittal Same as for traverse number. Note that the form is set up to handle Highway Department designations for control as well as Bridge Department. In place of the above, the Bridge Department will show the county and bridge number.

(6) Estimate Number Circle either "1st" or "2nd" to indicate whether it is estimate No. 1 or estimate No. 2.

(7) Design Section The Bridge Department will indicate the number of the design section. All Highway Department design sections are identified by a 99 printed on the form.

(8) Structure Circle the number identifying whether the estimate is "Substructure" or "Superstructure".

(9) Item This column is used to help identify the location of the bar and may also be used for further identification of the estimator. Care should be taken to keep the letters within the tic marks. If the estimator has no need of identification, this column should be left blank.

The name of the estimator can be put at the head of the item column. This is accomplished by making the size column read zero. As many lines of this type as necessary can be used for the identification.

(10) Size Columns 33 and 34 (indicated at the bottom) are headed "Size". Use the standard bar size number: #4 for 1/2" etc. When columns 35 to 38 are to be used for weight per foot show the number 99. (See the last two lines in Figure 6-442.1)

(11) Number Column Columns 35 to 38 are headed "number or wt/ft/ of wall". When using these columns for number of bars ignore the decimal by letting column 38 be the unit position. In Figure 6-442.1 the first item is 12 bars (not 1.2 bars). If 10,000 or more bars are to be reported use two lines, 5,000 in each line. When using the columns for wt/ft of wall column 38 indicates tenths of a pound per foot of wall. In Figure 6-442.1 the last item is 9.0 lbs/ft. (not 90 lbs/ft).

(12) Length Column Columns 39 to 42 are headed "Length". Column 42 indicates tenths of a foot in all cases.

6-442.2 TABULATED RESULTS A sample of the solution based on the data sheet shown in Figure 6-442.1 is illustrated in Figure 6-442.2. The "Card" column gives the number of cards used and is the basis for charges to the district for this service. Asterisks indicate totals for the length and weight of bars for each size as well as the grand total for the weight.

6-442.3 SUBMITTAL AND MAILING Data for computation of reinforcing steel quantities can be submitted together with traverse and/or four-factor computations. In general, these problems will be computed and mailed to the district on the same day the data is received. For instructions on mailing data is received. For instructions on mailing data to Headquarters, see Index No. 6-412.4.

Sheet 1 of 1

REINFORCING STEEL

Date 4-1-57

	Name	Phone		Bridge #	Est	Des.		
BRIDGE DEPT.	Joe Dokes	1957	59	141	(1st) / 2nd	6	(8) / 9	Substructure / Superstructure
			1 2	3 4 5 6 7	8	Sec 9-10	11	

		Dist	Gr	Batch	Tran.				
HIGHWAY DEPT.						1st. / 2nd	99	8 / 9	Substructure / Superstructure
		1 2	3	4 5	6 7	8	Sec. 9-10	11	

Dist. - County - Rte. - Sec.

Form BD-34 Rev.

ITEM	Size	Number or wt / ft of wall	Length	Total Length - Each Size #4	#5	#6	#7	#8	#9	#10	#11
JOE DOKES	0	0	0								
ABUT. 1 FTG. LONGIT	5	12	339								
TRANS J	11	48	113								
ST R	11	48	220								
WALL LONGIT	4	8	336								
VERT BK	11	48	114								
FR	4	16	115								
END	4	32	56								
SEAT LONGIT	5	15	336								
TRANS L	7	32	110								
J	7	32	56								
BK WALL LONGIT	4	16	336								
VERT F	4	116	616								
B	5	312	78								
ABUT. 1 RT. WW.	99	224	1500								
	99	90	1400								
Cols. - 12 - 32	33 - 4	35 - 8	39 - 42								
	Total lengths										
	Wt per. foot			0.668	1043	1502	2 044	2670	3 400	4.303	5.313
	Total wt per size										
	Total wt for sheet										

Note: For computing steel in standard retaining walls from the charts, give size of 99

SAMPLE DATA SHEET
FOR MACHINE COMPUTATION
OF REINFORCING STEEL QUANTITY

QUANTITY OF BAR STEEL

COUNTY DIST	BRIDGE NUMBER GR	BRIDGE NUMBER BATCH	BRIDGE NUMBER TRANS-MITTAL	DESIGN SEC.	ORIG. OR CHECKER	SUB. OR SUP.	SIZE BAR	ALPHABETIC DESCRIPTION	NO. OF BARS	LENGTH TO 1/10 FT	EXTENDED LENGTH TO 1/10 FT.	POUNDS OF STEEL BAR	POUNDS OF STEEL PER BAR. SUB. SUP. BRIDGE	CARD COUNT
59			141	6	1	SUB		JOE DOKES						
											*		*	
59			141	6	1	SUB	4	ABUT WALL LONGIT	8	336	2688	180		
							4	ABUT 1 WALL VERT FR	16	115	1840	123		
							4	ABUT 1 WALL END	32	56	1792	120		
							4	ABUT BK WALL LONGIT	6	336	2016	135		
							4	ABUT BK VERT F	16	66	1056	71		
											9392*		629*	
59			141	6	1	SUB	5	ABUT 1 FTG LONGIT	12	339	4068	424		
							5	ABUT SEAT LONGIT	5	336	1680	175		
							5	ABUT BK VERT B	32	78	2496	260		
											8244*		859*	
59			141	6	1	SUB	7	ABUT SEAT TRANS L	32	110	3520	719		
							7	ABUT SEAT TRANS J	32	56	1792	366		
											5312*		1085*	
59			141	6	1	SUB	11	ABUT 1 FTG TRANS J	48	113	5424	2882		
							11	ABUT 1 FTG TRANS ST R	48	220	10560	5611		
							11	ABUT 1 WALL VERT BK	48	114	5472	2907		
											21456*		11400*	
59			141	6	1	SUB	99	ABUT 1 RT WW	224	1500	336000	3360		
							99		90	1400	126000	1260		
											462000*		4620*	
													18593*	
													18593*	16*

TABULATION OF REINFORCING STEEL QUANTITY COMPUTATION

FOUR FACTOR COMPUTATIONS (6-450)

Quantity Computations (6-451)

6-451.1 TYPE OF COMPUTATIONS **The four factor computation service is used to compute and summarize quantities for retaining walls, abutments, bent footings, etc. It has been suggested for use in construction to compute:**

(a) Weigh Scale Quantities
(b) Preparing Excavation Slopes (Erosion Control)
(c) Preparing Roadside Areas (Roadside Development)
(d) Clearing and Grubbing
(e) Areas for Select Rock Protection
(f) Mixing, Spreading and Compacting (Cement Treated Base and Cement Treated Sub-grade)

This program will perform any of the following four types of computations involving four factors of six digits, and will maintain two-decimal accuracy. Mathematically, the combinations fall into these categories:

(a) A.B.C.D
(b) (A+B) . (C+D)
(c) (A+B+C) . D
(d) (A+B) . C . D

In addition to making the above computations and showing the individual calculated results, the results are summarized showing three classes of totals or two classes and the summation of factors A and B. (See exhibits) This ability to summarize or accumulate algebraically the individual calculations provides considerable flexibility and makes it possible to handle a large variety of mathematical computations.

6-451.2 PREPARATION OF DATA SHEET Data shall be submitted on Form WH67A2 in the manner prescribed below. If the District, Bridge Department or other offices find some other form more convenient, permission for its use should be requested from the Tabulating Section. For highway offices other than the Bridge Department, the controlled data should be recorded below "others use".

(1) General Instructions The instructions given under Index No. 6-412.2 regarding District Number, Group Letter, Batch Number and method of transmittal shall apply to this type of problem.

The blank block shown above "10", after "Transmittal", can be used for further control if necessary, otherwise it is to be left blank.

(2) Item Number Each individual calculation will be identified by an item number. There can be several calculations recorded with the same item number. These individual calculations will be summarized algebraically for:

(a) Each decimal item number,
(b) Each change in the units position of the item, and,
(c) For each change in tens position of the item.

By special request the last class of total will be eliminated and the factors A and B will be summated.

(3) Description Field The description field need not be used if it has no value to the individual submitting the computation. If used, abbreviations should be employed where possible. The letters should be recorded within the tic marks to assure that the number of columns allocated to description will not be exceeded.

(4) Problem Type One of the four problem types must be recorded in this column. Note that should any one of the four factors be omitted, this omission will have a different affect on the solution of the problem depending on the problem type.

A blank in any of the factor columns will cause the machine to recognize the value of the factor as either zero or one as tabulated below:

Factor	A	B	C	D
Problem Type				
1	1	0	1	1
2	0	0	0	0
3	0	0	0	0
4	1	0	1	1

A zero recorded in any of the factor columns will cause the machine to recognize the factor as zero or one as shown below:

Factor	A	B	C	D
Problem Type				
1	0	0	1	1
2	0	0	0	0
3	0	0	0	0
4	1	0	1	1

(5) Sign Each of the four factors is prefixed with a column captioned "Sign". These columns may be left blank if the sign is in fact plus (+). Minus signs will have to be recorded.

6-451.3 SAMPLE PROBLEMS The following are examples of methods of recording and of the output. They are not necessarily the type of problem which should be submitted for this calculating service. This will have to be decided by the engineer himself. However, they do demonstrate the potentiality of the service. The example for clearing and grubbing shows two solutions indicating a possible method of checking by using two different approaches.

(1) Clearing and Grubbing Computations Two approaches are shown below, both utilize the basic trapizoidal formula for the computation of areas. A typical area which is to be cleared and grubbed is shown on Figure 6-451.3A. The formulas applicable to this exhibit are as follows:

(a) Method 1 $A = 1/2\ b_1\ (h_1 + h_2)$

Where:

b_1 = Station $_2$ - Station $_1$

$h_1 = a_1 + a_2$

$h_2 = a_3 + a_4$

This method has two lines per section

1) (Sta. $_2$ - Sta. $_1$) $(a_1 + a_2)$
2) (Sta. $_2$ - Sta. $_1$) $(a_3 + a_4)$

Result is double area in same units as the input.

(b) Method 2 $A = 1/2\ b_1\ (h_1 + h_2)$

Where:

b_1 = Station $_2$ - Station $_1$

$h_1 = a_1 + a_2$

$h_2 = a_3 + a_4$

Equation A in acres $= 1/2 \cdot \frac{1}{43560} (S_2 - S_1)(a_1 + a_2 + a_3 + a_4)$

This method requires eight lines per section

1) $(S_2) \cdot (a_1)$ (1147.84)

2) $(S_2) \cdot (a_3)$ (")

3) $-(S_1) \cdot (a_3)$ (")

4) $-(S_1) \cdot (a_1)$ (")

5) $(S_2) \cdot (a_2)$ (")

6) $(S_2) \cdot (a_4)$ (")

7) $-(S_1) \cdot (a_4)$ (")

8) $-(S_1) \cdot (a_2)$ (")

$$\left(\frac{1}{(43560)} \cdot 2 = 1147.84 \times 10^{-8} \right)$$

Summation of calculations $\times 10^{-8}$ = acres to 1/100

Figures 6-451.3B and 6.451.3C show the method of recording the data and the tabulated results are shown on Figures 6-451.3D through 6.451.3G for different summations requested.

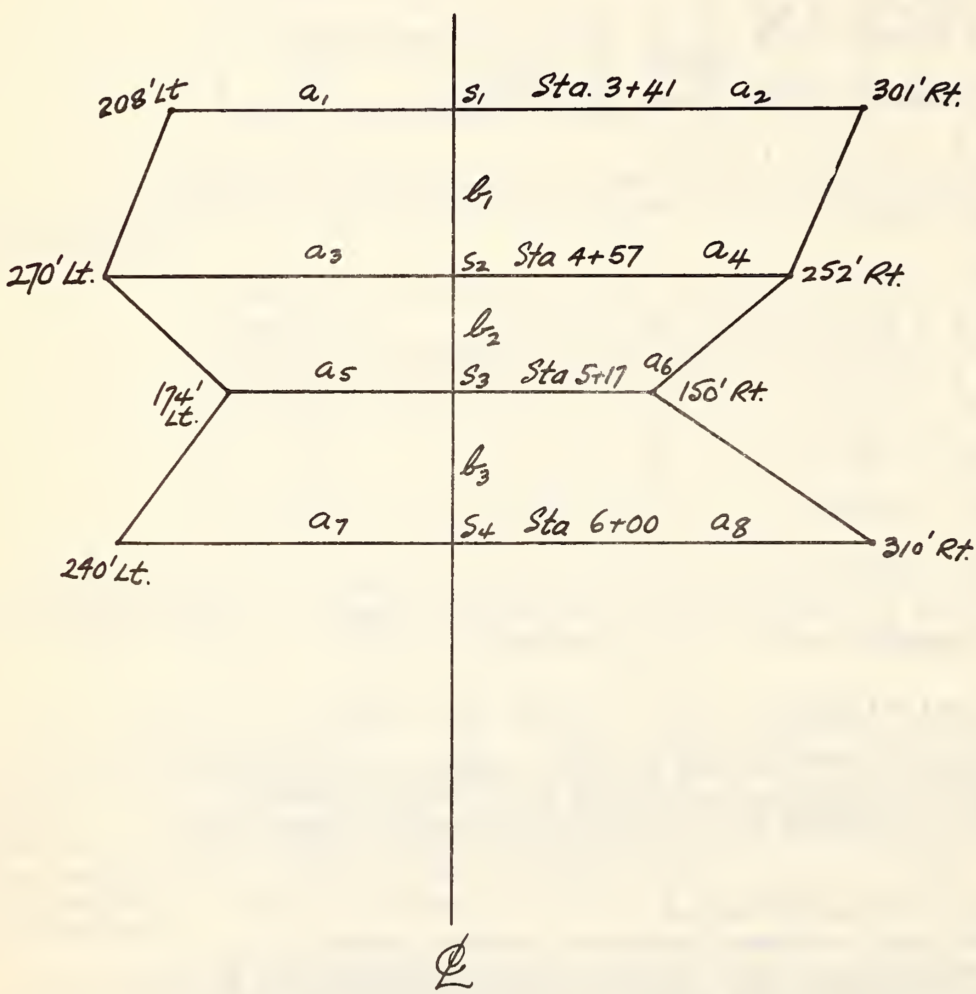
(c) Possible additional method

When the increment between station pluses is constant, submission of this problem can be simplified by breaking up the trapezoidal areas in Figure 6-451.3A into triangles and using Problem Type 3. In this case factor A becomes the distance left. factor B the distance right, factor C can be used for adjustments in distances due to top of cut ditches, etc., and factor D is the conversion factor to acres.

(2) Computing and Summarizing of Quantities This example is taken from the Bridge Department's memorandum to Designers dated March 19, 1957. Figure 6-451.3H shows the input data and Figures 6-451.3I and 6-451.3J are the tabulated results depending on the totals requested.

CLEARING AND GRUBBING USING 4 FACTOR COMPUTATION SERVICE

Sketch Illustrating Area to be Computed



COMPUTATION SHEET

Bridge use

Des. Sect. (1 2)

Bridge Number (3 4 5 6 7 8 9)

Computation Number (10)

Others use

Dist	Gp
99	1 3 5

(1 2 3 4 5)

Batch	Trans-mittal
0 1	0 1 -

(6 7 8 9 10)

Name: *Osofsky*

Phone: *2595*

Problem Type
1. A·B·C·D
2. (A+B)·(C+D)
3. (A+B+C)·D

Item (11 12 13)	Description (14-35)	Prob. Type (36)	Sign (37)	Factor A	Sign (44)	Factor B	Sign (51)	Factor C	Sign (58)	Factor D
000	CLEARING & GRUBBING									
000	OSOFSKY TWICE AREA									
010	A 1	3		457.00	-	341.00				208.00
"		3		"	-	"				301.00
"		3		"	-	"				270.00
"		3		"	-	"				252.00
011	A 2	3		517.00	-	457.00				270.00
"		3		"	-	"				252.00
"		3		"	-	"				174.00
"		3		"	-	"				150.00
112	A 3	3		600.00	-	517.00				174.00
"		3		"	-	"				150.00
"		3		"	-	"				240.00
"		3		"	-	"				310.00

WH 67 A2

Sheet 1 of 1

SAMPLE DATA SHEET FOR CLEARING AND GRUBBING COMPUTATION

First Method

SAMPLE DATA SHEET FOR CLEARING

Second

COMPUTATION SHEET

Bridge use

Des. Sect. (1 2)

Bridge Number (3 4 5 6 7 8 9)

Computation Number (10)

Others use

Dist Gp: 99 / 3 S (1 2 3 4 5)

Batch / Transmittal: 01 02 - (6 7 8 9 10)

Name: Osofsky

Phone: 2595

Problem Type
1. A·B·C·D
2. (A+B)·(C+D)
3. (A+B+C)·D

Item (11 12 13)	Description (14-35)	Prob Type (36)	Sign (37)	Factor A	Sign (44)	Factor B	Sign (51)	Factor C	Sign (58)	Factor D
000	CLEARING & GRUBBING									
	OSOFSKY MPY AREA BY									
	10 TO MINUS 8 FOR ACRE									
010	A 1	1		45700		20800		114784		
"		"		"		30100		"		
"		"		"		27000		"		
"		"		"		25200		"		
"		"	-	34100		20800		"		
"		"	-	"		30100		"		
"		"	-	"		27000		"		
"		1	-	"		25200		"		
011	A 2	1		51700		27000		"		
"		"		"		25200		"		
"		"		"		17400		"		
"		"		"		15000		"		
"		"	-	45700		27000		"		
"		"	-	"		25200		"		
"		"	-	"		17400		"		
"		1	-	"		15000		"		

WH-67-A2

Sheet 1 of 2

COMPUTATION SHEET

Bridge use

Des. Sect. (1 2)

Bridge Number (3 4 5 6 7 8 9)

Computation Number (10)

Others use

Dist Gp: 99 / 3 S (1 2 3 4 5)

Batch Transmittal: 0 1 0 2 - (6 7 8 9 10)

Name: Osofsky

Phone: 2595

Problem Type
1. A·B·C·D
2. (A+B)·(C+D)
3. (A+B+C)·D

Item (11 12 13)	Description (14-35)	Prob. Type (36)	Sign (37)	Factor A	Sign (44)	Factor B	Sign (51)	Factor C	Sign (58)	Factor D
112	A 3	1		60000		17400		114784		
"		"		"		15000		"		
"		"		"		24000		"		
"		"		"		31000		"		
"		"	–	51700		17400		"		
"		"	–	"		15000		"		
"		"	–	"		24000		"		
"		"	–	"		31000		"		

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Sheet 2 of 2

4 FACTOR COMPUTATION SERVICE

IDENTIFICATION (Bridge Number)	Computation Number	Item Number	Total Factor A / Description	Total Factor B	Factor A	Factor B	Factor C or C.C.	Factor D	Result
9913S0101			CLEARING & GRUBBING						
			OSOFSKY TWICE AREA						
9913S0101		10		3	45700	34100*		30100	3491600
		10	A 1	3	45700	34100*		20800	2412800
		10		3	45700	34100*		27000	3132000
		10		3	45700	34100*		25200	2923200
					Divide by 2 to get area in sq. ft.				11959600
9913S0101		11	A 2	3	51700	45700*		27000	1620000
		11		3	51700	45700*		35200	1512000
		11		3	51700	45700*		17400	1044000
		11		3	51700	45700*		15000	900000
									5076000
							Total Items 10 & 11		17035600
9913S0101		112	A 3	3	50000	51700*		17400	1444200
		112		3	60000	51700*		15000	1245000
		112		3	60000	51700*		34000	1992000
		112		3	60000	51700*		31000	2573000
									7254200
									7254200
					Number of calculations		14*		24289800

Decimal here

Divide by 2 to get area of Items 1 & 11

PROBLEM TYPE 1 A·B·C·D 2 (A+B)·(C+D) 3 (A+B+C)·D

E INDICATES A PRODUCT WHICH EXCEEDS ALLOWED SPACE

4020-64573

TABULATED RESULTS FOR CLEARING AND GRUBBING COMPUTATION

First Method : **Showing usual totals**

4 FACTOR COMPUTATION SERVICE

IDENTIFICATION: BRIDGE NUMBER	ITEM NUMBER	DESCRIPTION / TOTAL FACTOR A	TOTAL FACTOR B	PROBLEM TYPE	E = OVERFLOW	FACTOR A	FACTOR B	FACTOR C or C.C.	FACTOR D	RESULT
9913S0101		CLEARING & GRUBBING								
		OSOFSKY TWICE AREA								
9913S0101	10			3		45700	34100 *		30100	3491600
	10A	Sum of A & B		3		45700	34100 *		20800	2412800
	10			3		45700	34100 *		27000	3132000
	10			3		45700	34100 *		25200	2923200
		182800	136400		*					11959600
9913S0101	11A 2			3		51700	45700 *		27000	1620000
	11			3		51700	45700 *		25200	1512000
	11			3		51700	45700 *		17400	1044000
	11			3		51700	45700 *		15000	900000
		206300	182800		*					5076000
Sum of Items 1.0 & 1.1 →		389600 →	319200		*					17035600
9913S0101	112A 3			3		60000	51700 *		17400	1444200
	112			3		60000	51700 *		15000	1245000
	112			3		60000	51700 *		24000	1992000
	112			3		60000	51700 *		31000	2573000
		240000	206800		*					7254200
		240000	206800		*					7254200
								14 *		

Obtain sum of these and divide by 2 if area of Items 1 & 11 are required in sq. ft.

PROBLEM TYPE 1 A·B·C·D 2 (A+B)·(C+D) 3 (A+B+C)·D

E INDICATES A PRODUCT WHICH EXCEEDS ALLOWED SPACE

4020-64573 WH 72 112

TABULATED RESULTS FOR CLEARING AND GRUBBING COMPUTATION

First Method: Showing totals obtained by special request

4 FACTOR COMPUTATION SERVICE

IDENTIFICATION (Design Section / Bridge Number: District, GA, Batch, Transmittal / Computation Number)	ITEM NUMBER	TOTAL FACTOR A / DESCRIPTION	TOTAL FACTOR B	PROBLEM TYPE	FACTOR A	FACTOR B	FACTOR C or C.C.	FACTOR D	RESULT
9913S0102		CLEARING & GRUBBING							
		OSOFSKY HPY AREA BY							
		10 TO MINUS 8 FOR ACRE							
9913S0102	10	A 1		1	45700	20800	114784		10910907904
	10			1	45700	30100	114784		15789342688
	10			1	45700	27000	114784		14163197760
	10			1	45700	25200	114784		13218984576
	10			1	34100*	20800	114784		8141399552*
	10			1	34100*	30100	114784		11781544544*
	10	Algebraic Sum of A & B		1	34100*	27000	114784		10568162880*
	10			1	34100*	25200	114784		9863618688*
		46400	206200						13727707264
9913S0102	11	A 2 — Decimal Here		1	51700	27000	114784		16022698560
	11			1	51700	25200	114784		14954518656
	11			1	51700	17400	114784		10325739072
	11			1	51700	15000	114784		8901499200
	11			1	45700*	27000	114784		14163197760*
	11			1	45700*	25200	114784		13218984576*
	11			1	45700*	17400	114784		9127394112*
	11			1	45700*	15000	114784		7868443200*
		24000	169200						5826435840
Total Item 1.0 & 1.1 →		70400	375400						19554143104
9913S0102	112			1	51700*	31000	114784		18396431680*
	112	A 3		1	60000	17400	114784		11983449600
	112			1	60000	15000	114784		10330560000
	112			1	60000	24000	114784		16528896000
	112			1	60000	31000	114784		21349824000
	112			1	51700*	17400	114784		10325739072*
	112			1	51700*	15000	114784		8901499200*
	112			1	51700*	24000	114784		14242398720*
		33200	174800						8326660928
		33200	174800						8326660928
							27*		

If sum of A and B are obtained — lose this total → Total of Items 1 & 11 to be obtained manually as sum of A & B were requested.

PROBLEM TYPE 1 A·B·C·D 2 (A+B)·(C+D) 3 (A+B+C)·D

E INDICATES A PRODUCT WHICH EXCEEDS ALLOWED SPACE

4020-64573

TABULATED RESULTS FOR CLEARING AND GRUBBING COMPUTATION

Second Method: **Showing totals obtained by special request**

4 FACTOR COMPUTATION SERVICE

IDENTIFICATION: Design Section / Bridge Number (District, GR, Batch, Transmittal)	Computation Number	ITEM NUMBER	TOTAL FACTOR A / DESCRIPTION / TOTAL FACTOR B	Problem Type	E = OVERFLOW	FACTOR A	FACTOR B	FACTOR C or C.C.	FACTOR D	RESULT
9913S0102			CLEARING & GRUBBING							
			OSOFSKY MPY AREA BY							
			10 TO MINUS 8 FOR ACRE							
9913S0102		10	A 1	1		45700	20800	114784		10910907904
		10		1		45700	30100	114784		15789342688
		10		1		45700	27000	114784		14163197760
		10		1		45700	25200	114784		13218984576
		10		1		34100*	20800	114784		8141399552*
		10		1		34100*	30100	114784		11781544544*
		10		1		34100*	27000	114784		10568162880*
		10		1		34100*	25200	114784		9863618688*
							In Acres Decimal here			13727707264
9913S0102		11	A 2	1		51700	27000	114784		16022698560
		11		1		51700	25200	114784		14954518656
		11		1		51700	17400	114784		10325739072
		11		1		51700	15000	114784		8901499200
		11		1		45700*	27000	114784		14163197760*
		11		1		45700*	25200	114784		13218984576*
		11		1		45700*	17400	114784		9127394112*
		11		1		45700*	15000	114784		7868443200*
							Total of Item 1.1			5826435840
							" " Items 1.0 & 1.1			19554143104
9913S0102		112		1		51700*	31000	114784		18396431680*
		112	A 3	1		60000	17400	114784		11983449600
		112		1		60000	15000	114784		10330560000
		112		1		60000	24000	114784		16528896000
		112		1		60000	31000	114784		21349824000
		112		1		51700*	17400	114784		10325739072*
		112		1		51700*	15000	114784		8901499200*
		112		1		51700*	24000	114784		14242398720*
							Total of Item 11.2			8326660928
							Same since no other Item 11			8326660928
						Number of calculations →	27*			27880804032
							Total of Items 1 & 11			

PROBLEM TYPE 1 A·B·C·D 2 (A+B)·(C+D) 3 (A+B+C)·D

E INDICATES A PRODUCT WHICH EXCEEDS ALLOWED SPACE

WH 72-112

4020-64573

TABULATED RESULTS FOR CLEARING AND GRUBBING COMPUTATION

Second Method: **Showing usual totals**

COMPUTATION SHEET

Bridge use

Des. Sect.: 6 (columns 1 2)

Bridge Number: 5 9 1 4 0 0 1 (columns 3 4 5 6 7 8 9)

Computation Number: 1 (column 10)

Others use

Dist Gp: 99 (columns 1 2 3 4 5)

Batch Transmittal: (columns 6 7 8 9 10)

Name: Joe Dokes

Phone: 1957

Problem Type
1. A·B·C·D
2. (A+B)·(C+D)
3. (A+B+C)·D

Item (11 12 13)	Description (14-35)	Prob Type (36)	Sign (37)	Factor A	Sign (44)	Factor B	Sign (51)	Factor C	Sign (58)	Factor D
51	Struct Excavation	1		400		1000		2900		
"	" " Triangle	"		400		500		1400		50
"2	" " Bent 2	"		500		1400		1400		400
" "	" " 3	"		600		1200		1400		300
161	PCC Abut 1 Ftg	1		233		800		2700		
"2	" " Wall Rectang	"		125		1600		2400		
" "	" " Triangle	"		133		1600		2400		50
230	Girder Mid Top Pl	1		125		1400		2800		800
	" " Bot "	"		225		2200		3100		800
	" End Top "	"		88		1400		2500		800
	" " Bot "	"		113		2200		2350		800
				Ftg. Elev		Zip Elev				
250	Piles Vert Abut 1	2		24517		19900		4200		
"1	" Botter "	"		"		"		4450		
								No. x Batter Factor		
001	Joe Dokes									
002	Prem Quan Jan 17 1957									

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Sheet 1 of 1

SAMPLE DATA SHEET FOR MISCELLANEOUS QUANTITY COMPUTATIONS

4 FACTOR COMPUTATION SERVICE

Identification: Bridge Number	Computation Number	Item Number	Description / Total Factor A	Problem Type	Total Factor B (E = Overflow)	Factor A	Factor B	Factor C or C.C.	Factor D	Result
65914001	1	1	JOE DOKES							
65914001	1	2	PREM QUAN JAN 17 1957							
65914001	1	51	STRUCT EXCAVATION	1		400	1000	2900		116000
		51	STRUCT EXCAVATION TRI	1		400	500	1400	50	14000
			300		1500					130000
65914001	1	52	STRUCT EXCAVAT BENT 2	1		500	1400	1400	400	392000
		52	STRUCT EXCAVAT BENT 3	1		600	1200	1400	300	302400
			1100		2600					694400
			1900		4100					824400
65914001	1	161	PCC ABUT 1 FTG	1		233	800	2700		50328
			233		800					50328
65914001	1	162	PCC ABUT WALL RECTANG	1		125	1600	2400		48000
		162	PCC ABUT TRIANGLE	1		133	1600	2400	50	25536
			558		3200					73536
			491		4000					123864
55914001	1	230	GIRDER MID TOP PL	1		125	1400	2800	800	392000
		230	GIRDER MID BOT PL	1		225	2200	3100	800	1227600
		230	GIRDER END TOP PL	1		88	1400	2500	800	246400
		230	GIRDER END BOT PL	1		113	2200	2350	800	467368
			551		7200					2333368
			551		7200					2333368
65914001	1	250	PILES VERT ABUT 1	2		24517	19900 *	4200		193914
			24517		19900	*				193914
65914001	1	251	PILES BOTTER ABUT	2		24517	19900 *	4450		205457
			24517		19900	*				205457
			49034		39800	*				399371
								15 *		

PROBLEM TYPE 1 A · B · C · D 2 (A + B) · (C + D) 3 (A + B + C) · D

E INDICATES A PRODUCT WHICH EXCEEDS ALLOWED SPACE

4020-64573 WH 72 112

TABULATED RESULTS FOR MISCELLANEOUS QUANTITY COMPUTATIONS

Showing totals obtained by special request

4 FACTOR COMPUTATION SERVICE

Identification: Bridge Number	Computation Number	Item Number	Total Factor A / Description / Total Factor B	Problem Type	E = Overflow	Factor A	Factor B	Factor C or C.C.	Factor D	Result
6591 4001	1	1	JOE DOKES							
6591 4001	1	2	PREM QUAN JAN 17 1957							
6591 4001	1	51	STRUCT EXCAVATION	1		400	1000	2900		116000
		51	STRUCT EXCAVATION TRI	1		400	500	1400	50	14000
										130000
6591 4001	1	52	STRUCT EXCAVAT BENT 2	1		500	1400	1400	400	392000
		52	STRUCT EXCAVAT BENT 3	1		600	1200	1400	300	302400
										694400
										824400
6591 4001	1	161	PCC ABUT 1 FTG	1		233	800	2700		50328
										50328
6591 4001	1	162	PCC ABUT WALL RECTANG	1		125	1600	2400		48000
		162	PCC ABUT TRIANGLE	1		133	1600	2400	50	25536
										73536
										123864
6591 4001	1	230	GIRDER MID TOP PL	1		125	1400	2800	800	392000
		230	GIRDER MID BOT PL	1		225	2200	3100	800	1227600
		230	GIRDER END TOP PL	1		88	1400	2500	800	246400
		230	GIRDER END BOT PL	1		113	2200	2350	800	467368
										2333368
										2333368
6591 4001	1	250	PILES VERT ABUT 1	2		24517	19900*	4200		193914
										193914
6591 4001	1	251	PILES BOTTER ABUT	2		24517	19900*	4450		205457
										205457
										399371
								15*		3681003

PROBLEM TYPE 1. A·B·C·D 2. (A+B)·(C+D) 3. (A+B+C)·D

E INDICATES A PRODUCT WHICH EXCEEDS ALLOWED SPACE

WH 72-112 4020-64573

TABULATED RESULTS FOR MISCELLANEOUS QUANTITY COMPUTATIONS

Showing usual totals

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Ben. W. Steele
Assistant Engineer--Electronic Computing Section
Oklahoma Department of Highways

COMMENTS ON ORGANIZATION OF A COMPUTER SECTION, AND IT'S PLACE IN THE HIGHWAY ORGANIZATION. PRECEEDED BY A BRIEF SUMMARY OF OKLAHOMA'S PROGRESS IN THIS FIELD.

The Oklahoma Department of Highways installed the Remington Rand Univac 120 and accompaning equipment in the latter part of November 1956. Keypunch operators were hired December 1, 1956. Prior to this, one man had attended a two-week programing school on the 120, held by Remington Rand in Dallas, Texas. That same man accompanied by members of the Minnesota State Highway Department and representatives of Remington Rand, spent one week with the Arizona State Highway Department familiarizing themselves with Arizona's procedure on the Remington 120 Computer.

January 1, 1957, Mr. Towne, our accounting representative, started utilizing the computer for the accounting department.

In April 1957, another man was sent to Dallas to the Remington Rand programing school.

By March, two pilot jobs of earthwork had been checked through, with satisfactory results. Since then several earthwork jobs have been processed through the computing section with good results.

We have a standard structure program, that is to say this program will figure length and material of any standard straight, or skewed structure, as well as extensions. This program has proved very satisfactory.

We have a storm sewer program that figures cubic feet of water passing through the inlet per second (Q). By use of this program a set of tables for values of (Q) can be developed using all possible variables.

A program has been set up and tested for checking the contractors' bids on highway projects. This work has been delayed due to difficulty in obtaining material to produce offset plates on the model three tabulator. But delivery has now been promised, and we plan to start this operation October 1, 1957.

Right-of-Way has been our most recent endeavor. We have straight alinement right-of-way programs tested, a pilot job has been completed with satisfactory results. Curved right-of-way programs have been worked out, boards wired and a few of the many complex curved conditions have been checked through. Results were good and we feel that in a short time we will have the right-of-way problem under control.

Our next endeavor will be in the line of bridge work, some thought has been given to the matter, but no actual programing done as yet.

This has been a brief generalization of our efforts to date. I will attempt to cover in detail the important aspects next.

ACCOUNTING:

At the present the accounting department is running maintenance cost, depreciation, fuel consumption, etc., as a regular cycle. Each week they have a two-day priority on the computing equipment. This does not mean that it takes two days each week to do the accounting, rather that they have first priority on the equipment on these two days.

EARTHWORK:

Our current earthwork procedure is as follows: While the design squads are plotting and inking the topography, the keypunch operators are punching the rodreading cards. Two cards are punched for each station, one right and one left. We use rodreadings instead of elevations, this gives much greater capacity to each card. After the rodreading cards are completed they are stored until such time as the design squad gets the soils reports. Then with the help of the soils report the design squad can give us the typical section, P.I. stations and elevations, grade rates between P.I., length of vertical curves, maximum vertical curve correction, rock swell and compaction factor. This information is coded into the level books and then a grade card is punched for each station that we have rodreading cards for, as well as all curve and P.I. control cards. From this time on it is a machine operation, which takes approximately 45 minutes per mile to come up with the following information, which is returned to the design squads in three separate forms. The information is printed horizontally across the forms as follows: Form one, station number, State work order number, super rate per foot, amount of widening in feet, and corrected grade elevation at that station. The second form has, station number, rock swell, compaction factor, true volumes, both cut and fill in cubic yards, total end area both cut and fill in square feet, to the nearest tenth of a square foot, cross over distance (point where fill or back slope hits natural ground), and elevation at that cross over point. This is given for right and left at each station. Adjusted volumes, both cut and fill, and a mass ordinate at that station. The third form contains only information for full stations and comes as follows: Station number, plotted point and mass ordinate value. This plotted mass line, is sufficient to evaluate the choice of grades and to determine if any changes are necessary. This program will handle alinement or elevation equations, as well as variable cut and fill slopes.

STRUCTURES:

The structure program, starting with the same basic information that is used to figure manually the length and quantities of reinforced concrete box (R.C.B.), corrugated galvanized metal pipe (C.G.M.P.), or reinforce concrete pipe (R.C.P.). The 120 takes the input information for each structure on one card and the following card receives the answers, these cards are segregated automatically. Allowance is made for the fact that our R.C.P. and C.G.M.P. comes in different joint length and that they use different thickness headwalls. The output information consists of station number, roadway right and left, total roadway, and (if the structure is pipe), the number of feet of pipe required, the number of construction joints, if the structure is a R.C.B., in either case the total concrete and steel is figured. This output information is easily transferred from the form sheet to the pay quantity sheet and structure notes.

STORM SEWER:

As we already had a set of tables for storm sewer quantities, this program has been used primarily for extension of these tables, and as a selling point of the effeciency of the electronic computer.

CONTRACT LETTING:

When the contract letting program is put into use, the electronic computing section should be able to do in a few hours, the work that has formelly utilized the time of the entire personnel of the road plans section. This should result in a saving of many man hours each month.

RIGHT OF WAY:

In the right of way work, one eight mile, straight alinement pilot project has been completed. We feel that this application when its full potentiality has been reached, will be more rewarding per man hour invested than any other. Let us consider the pilot project for an example of results obtained. Two men obtained in one and one half hours all necessary information from the plans. One keypunch operator punched and another operator verified this information, in approximately one and one half hours. The computer made the necessary calculations in approximately five minutes, making a total of approximately three and one half hours. Now let us see what we received for this effort. The output information ran as follows: The lengths and bearings of each course, as well as the area between it and the section line or center line which ever was used. This information is grouped by easement number and a total of area is given for each easement. Corrections are made for a section line paralleling or nearly parralleling the center line. This program takes care of all property lines, section or quarter section lines, intersecting the right of way, regardless of the angle of intersection. This was a simple project in that it had no curves, but also bear in mind that it was the first, and as we become more familiar with our proceedings our effeciency will improve.

This is a brief summary of our progress to date. Now to the subject at hand (organization of a computer section, and its place in a Highway Engineering Organization.)

The fact that we are gathered here to discuss this and other subjects of equal importance is proof enough that the need exists for such organizations. I am participating in this discussion, not because I feel that I am an authority on this matter. But I am participating because I maintain a sincere belief that the proper organization of a computer section, is with in itself, the most important step that we will make in this inevitable change to automation in the engineering field. Not only do I feel the importance of this organization, but also that as we are making this transition that we are provided with an opportunity to do a little house cleaning on our present methods, and bring them up to date. What do I mean? Now I will ask a question you answer it for yourselves, to yourselves. But consider it well. How many times have your subordinates come to you with the question,"Why do we do this in this manner?" Meaning our approach to some of our problems, and you give them the stock answer, because we have always done it this way. I am sure that in many instances the method is still alright. But shouldn't our answer be,

"Because to the best of our knowledge this is the best way to do this particular job."? We trade our old automobiles for new and better ones, but all to often we are content to use the approach to a problem that our predecessors worked out. Organization is important from the stand point, that when we have developed a pattern of behavior, we find it hard to change. So we should start right if possible. Another thought is that we should not let our new computer section become top heavy.

I have chosen to divide my remarks into four groups.

1. The decision to organize a computer section and the equipment to install.

2. Personnel to head and operate computer section.

3. Those that will be utilizing the computer section's services.

4. The computer representatives.

1.

The decision to organize a computer section should be prompted by one and only one thing, the need of such a section. After this need has been established, then a complete analytical study should be made of the kind and amount of equipment to be installed. I would suggest that you take the following approach in obtaining the necessary information on which to base your decision: By writing to the various highway departments, or to the private engineering companies that are currently using electronic computing equipment. Particularly to those having similar problems as those existing in your department. You might ask them if their computer fulfilling their present needs, is the manufacturer giving adequate service? What is your percent of down time? Will it fulfill your future needs? Did the computer company oversell you? Has your equipment come up to your expectations? Does the use that you deriving from your equipment justify the cost? Now this matter of cost you might say, isn't the prime factor. But consider with me for a moment the top heavy aspect of this thing. If you install a large and expensive computer, with all accompaning equipment, and a large staff of personnel. If then you are not able to produce, you may defeat your own purpose. By creating a white elephant, that could set back or completely destroy the chances of an effecient organization. Now no one would deny that the larger computer and accompaning equipment has a greater capacity, hence a greater potentiality. But you must determine whether or not your need, and your ability to utilize a computer will justify a large or small one. Now that you have made the decision concerning the equipment, personnel is next.

11.

Opinions will probably vary considerably on the choice of personnel to head and operate the new computer section. In my opinion the man to head this section should have a degree in engineering, mathematics, or an equivalent in experience. He must entusiastically accept the idea of automation, otherwise he is apt to find it extremely difficult to forsake his stereotyped ideas of conventional engineering procedure. To obtain efficient results from the electronic computer, it is essential that he think as the computer thinks. I do not believe it necessary to start with to large a staff of personnel, for the following reasons. When the section is in it's infancy,

there are many problems to be solved, pertaining to the organization, that must be solved before the engineering work can be considered. Personnel must be trained for the various machines. I realize that at this time there exists many working programs, pertaining to our various engineering problems. But it is essential that they be understood, then adapted to your specific problems. Next a pilot project for each application, or program must be completed and checked. Gentlemen, this is a time consuming task. This must be done for each department that you expect to work with, right of way, road plans, bridge, etc..

When you have worked these pilot projects out to your satisfaction, then comes waht well might be the most difficult problem that you are to face, selling the various departments on the desirability of utilizing your computer service. Now this transition period takes considerable time, and should you be carrying a large overhead of personnel and equipment, your computer section might become top heavy to the extent of defeating itself before it could produce. At the present time many universities are offering courses in computer programming. The various computer manufacturers maintain programming schools, for those participating, or desiring to participate in the use of their equipment. It should not be extremely difficult to obtain semi-trained personnel when needed. I know of no computer manufacturer that will not lease you additional equipment as the need arises. My thought then is to have a qualified man in charge, start him out with enough personnel and equipment to carry out the pilot projects, then let him add additional equipment and personnel as his needs justify, also wage scale should be established that will eliminate as much as possible, an excessive turnover in personnel.

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To the men of the various departments that are to utilize the services of the computer section. First I would say, the computer is not an engineering replacement, rather it is a supplement or aid. It, when fully utilized, will perhaps change the proceedure of obtaining the end result. But the fact remains that the end result must be reached since the computer can only do repetitious woek, and has no power to reason, then it mustremain your helper, not your master. But just as the automobile replaced the horse and buggy, so will the electronic computer replace some of our present methods of obtaining the answers to our engineering problems. Some are inclined to say, "We know that our present methols are O.K., of this new method we know nothing", so said people of the Wright Brothers' desire to fly. But we of today have just about conceded that the airplane is here to stay. My thoughts are, that when you have had your respective problems worked, and proved to your satisfaction on the computer, then and only then, accept the computer for what it is, a good and useful modern tool. You will find upon close compaarison that in some respects the old maethods are stronger, but when the tally is made, that the count will be in favor of the computer. You will find too, that upon taking full advantage of the abilities of the computer that it will aid both you and the engineering field as a whole.

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Now to the computer representives, I have this to say, it is natural for mankind to distrust, yes even resent the things that he does not understand. In the face of this, I find some trying to use this lack of knowledge, as a selling point. How you ask, are we guilty of this? Permit me to elaborate on this for awhile. By taking a group of prospective customers (engineers), you start comparing the computer time required to do a given problem, to the time required of an engineer to do the same thing. But you neglect to mention the time and effort required to organize the computer section, the time that went into the programming of that problem, the time consumed in obtaining and keypunching the input inforamtion into a usable form for the computer, the time consumed in the various other machine operations, sorting, etc., nor do you mention the time consumed in setting up, and tabulating your results. I would also like to say, that unless the personnel of the computer section carry out all of these accompaning operation correctlly, the computer is helpless to produce correct results, the result of incorrect input, is the incorrect output. Now in comparing a few seconds of computer time, to a few hours of a engineer's time, you have at best antagonized him. Now about this time you have the administrative staff half sold, and half dazed with these illusions of grandeur, results, they ask for a demonstration of this miracle, fully expecting to see you wave a wand, and produce a completed set of road plans. Then at times you find it necessary to tell them that there remains a couple of minor details to be worked out before you can produce, however, they are assured that upon installation, a wand will be waved, and these details will vanish. What, you ask is wrong with this? In the first place the implication has been made that compared to the computer, that an engineer isn't important, as a result of not being able to produce at the proper time, you have an antagonized, and distrusting engineer, this man must later be sold by the computer section at a time when they badly need his help, and cooperation in producing usable results. Gentlemen this need not be, the computer industry has produced, and are continuing to produce a product that need not be over sold, now apologized for, It can and will lighten the engineering burden, if properly applied. It has, and will continue to make available new avenues of research in the engineering field. I would go so far as to say that the computers of today are the horse and buggies of times past, they in my opinion have unlimited future.

The computer section's place in th Highway Organization:

Since most highway organization's are composed of various departments, it is a natural thing for a lack of cooperation to exist between departments or individuals, from time to time, keeping in mind that the new computer section is going to have troubles of it's own. Now the ultimate aim is to do work for all departments. To obtain these results the computer section must have the cooperation of these respective departments. The computer section can not be obligated to, or by any of these department, The only answer then is that of necessity, the computer section must be a seperate unit working with, not for the other departments. We come now to the

planning of work flow through the computer section. Potential alone is not enough, the work must come, in such a manner that it can be handled systenmatically. Example: Lets say the right of way department brings in a job to be completed each day. This required every operation peculiar to this type of job, to be completed each day. But had this work been brought in daily, keypunched at the computer section's convenience during the week, then on a given day all this work is processed, requiring one tab setup instead of six, considering of course that on many projects more time is required for the setup, than is for the tab operation. This comparison can be carried throughout all of the operations required in any job.

The net result is a great saving of time and elimination of human error through systenmatic channalization.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Discussion on

Obtaining the Optimum Value from Photography and Photogrammetry in Highway Engineering

Moderator

W. T. Pryor--U. S. Bureau of Public Roads

C. W. Whitcomb--Massachusetts Department of Public Works

Vinton A. Savage--Maine State Highway Commission

Robert H. Sheik--Ohio Department of Highways

A. O. Quinn--Aero Service Corporation
Philadelphia, Pennsylvania

G. E. MacDonald--Lockwood, Kessler & Bartlett
Syossett, New York

Conference on Increasing Highway Engineering Productivity
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William T. Pryor
Bureau of Public Roads

Ladies and Gentlemen - This afternoon our first panel is on "Obtaining the Optimum Value from Photography and Photogrammetry in Highway Engineering." I think most of you are informed regarding work that has been done the past several years in utilization of photogrammetry in general throughout the United States. Fortunately, we have had our attention focused on such utilization, particularly the last year, in conjunction with electronic methods of computation. The dove-tailing of photogrammetry and electronic methods of computation are natural consequences, because full and effective use of photogrammetry in making aerial surveys for highways provides locators, designers, and electronic engineers with all essential dimensions to the accuracies needed, when required.

We are fortunate this afternoon in having here five competent men who will tell us their experiences in obtaining qualitative information and quantitative data (dimensions) as needed by use of photography and photogrammetry in highway engineering.

As a part of the program, it would be worth-while, however, for me to tell you about a new instrument recently developed to fulfill a vital need, and which will be available this month to all users of photographs. This instrument will enable each of us to get more than ever before, both qualitatively and quantitatively, from aerial photographs.

We have always had need for the perfect medium of recording qualitative information and quantitative data together in composite form. Perhaps such a medium has not yet been conceived, and certainly, it has not been developed. Today, however, we do have photographic materials which, if they could be fully used in all their potential, would come close to being the perfect recording medium. Many of the limitations occuring in photographic materials (emulsions on transparent base such as film and smooth flat glass, and on opaque base such as paper) arise as a consequence of our inability to produce an even distribution of light throughout an exposed area. This is particularly evident when photographic film is exposed from an air station for the purpose of obtaining negatives to print aerial photographs.

We are all familiar with the light falloff principle in which lenses transmit more light to the center than to areas near or at the edges of the photographic negative. Falloff in light intensity reaching the photographic emulsion varies as the fourth power of the cosine of the angle between the

light ray and the optical axis of the camera being used to expose the photographic negative. In addition, we are all familiar with the inadequacy of our usual methods of transferring photographic images, by a printing process, from negative to positive form to obtain equal minuteness of detail in the dark tone areas, light tone areas, and the intermediate tones. People of many different qualifications, interests, and purposes have been engaged in efforts through thinking, experiment, and variation of methods and procedures to attain the utmost from photographic materials. Through these efforts of the many, great strides have been made in the improvememt of photographic emulsions and base materials of negatives and positives. Attaining the ultimate from the available photographic emulsions is the current problem we must solve.

Today, perhaps,greatest progress yet to be made lies in the improvement of methods and techniques of printing the positive from the negative. In the processes of printing aerial photographs on opaque paper and on transparent film and glass, there always has been the vital and greatly increasing need for an exposing light source which can be easily controlled. It must be controlled at an intensity inversely proportional to the light density of the photographic negatives from which the photographic prints are required. This need has existed since the advent of photography over a century ago, and has been accentuated considerably since aerial photography has been introduced as an important source of qualitative information and quantitative data for engineering and other purposes.

Many principles have been applied, procedures devised, and methods and systems developed for the purpose of attaining the utmost detail in photographic prints from every type, quality and density of photographic negative. Some measures of success have been achieved by employing variations in photographic emulsion, in type of exposing light and its control, and in developing processes. Eventually, the many and various innovations and manipulations were classed as an art in dodging, attainable by the experienced who tried every procedure and device that could be devised or learned about from someone else. Amazing results were achieved in subtle ways, but not before lengthy trial and error through repeated (thus costly) use of the best available materials. Many trial prints had to be made before an acceptable print was produced, each at considerable cost in both material and time. The causes of these unfortunate situations are the fact that consistency could seemingly never be achieved. Furthermore, for some classes of printing, especially in the making of transparencise on glass for use in stereophotogrammetric instruments, two prints were made routinely as greater assurance that an acceptable print would be attained--and all this seemingly wasteful practice was employed by the best qualified photographic laboratory technicians using the best materials and equipment available.

Until quite recently, dodging to restrict light on thin (light-transparent) portions and to admit more light or to cause longer exposure by light in the dark (dense) portions of photographic negatives has been accomplished:

(1) by manual dodging using the hands, wands, templets, and so forth.

(2) by varying in printing equipment, the multiple light sources which can be turned on or off in many combinations according to the operator's judgment.

(3) By using an unsharp positive initially printed from the negative and placed back of the negative as a mask, a physical means to regulate the light passing through the negative for more even exposure of the emulsion on the photographic print, and

(4) by using a battery of built-in light meters to measure negative density (light transmissibility), or from another point of view, to measure the intensity of light required to pass through the negative and expose the emulsion with which the print is to be made and then regulate a corresponding battery of lights for controlled exposure of the photographic emulsion in the greatest uniformity possible.

Except for the unsharp positive used as a mask, the other methods were limited in their dodging ability by the size of the dodging materials, the skill with which they could be manipulated, and the minimum size of area that could be illuminated with control. Deficiencies in each method were compensated for as much as possible by skill in processing the light exposed emulsions in development, stop bath, and fixing solutions.

In addition to the previously mentioned methods, one of the most promising strides made toward achievement of automatic dodging, regardless of the type and quality of negative, was attained when the electronic type of dodger was invented and made available. This photographic dodging instrument employs a light sensitive device to regulate the intensity of a scanning dot of light by the feed-back principle. In a sense, a positive image of the negative is registered on the face of a cathode ray tube. This is done somewhat inversely to the density of the negative, and achieves as much dodging as the size of the intensity-regulated, emulsion-exposing, dot of light will admit. The size of the dot, however, limits the minuteness of photographic detail which can be instantaneously dodged. This limitation has the apparent effect of causing a "border halo" at places where there is a line-type demarcation between extreme contrasts in negative density.

Fortunately, current developments in the application of a much earlier known principle to a new photographic dodging instrument are now successful. No "border halo" problem exists because of "dot size", and a minute detail in the black and white negative can be effectively dodged.

Let me describe the principles governing this new photographic dodging instrument. It is the latest development with promises of fulfilling more of our dodging needs than ever before. Photographic dodging is accomplished by this instrument through utilization of fluorescence. Consequently, it has been named the Fluoro-Dodge by its inventor and producer, the Watson Electronics and Engineering Company of Arlington, Virginia.

Fluorescence is a phenomenon that was noted over a century ago. Discoveries regarding the principles of fluorescence and the fact that it can be quenched are described in Volume 9 of the 1950 edition of the Encyclopedia Britannica. Briefly, the discoveries are: In 1652 "Zecchi illuminated phosphors with light of different colors and found that the color of the phosphorescent light (light emitted) was the same in each case." It was not until 200 years later that Sir George Stokes discovered that fluorescent bodies behaved in the same way. Before 1810, Thomas Seebeck discovered that red light destroyed the luminosity of an illuminated phosphorescent substance. This discovery remained comparatively unknown for many years and was rediscovered and investigated by A. H. Becquerel who lived 1852-1903, and who was awarded jointly with Pierre Curie a Nobel prize in 1903 for discoveries regarding uranium. In 1904, A. Dahms found that a zinc-sulphide phosphorescence was quenched by red light. P. Lenard further discovered that a phosphor excited to luminosity by ultraviolet light converted this short wave length light into light of a longer wave length.

Actually, fluorescence is an absorption by fluorescent substances of light in one wave length and simultaneous re-emission of light in a longer wave length. The intensity of the light emitted from fluorescent material activated by ultraviolet light can be controlled in an inverse proportion to the intensity of an opposing (quenching) infrared light. In reality, the Fluoro-Dodge works on this principle of fluorescence and the fact that the fluorescent light is quenched, retarded in emission intensity, by red and infrared light rays.

Although the phenomenon of fluorescence had not been utilized previously for the dodging of photographic negatives for production of better quality positives, the principle has been used and developed to the status of successful demonstration within the past six months. An ultraviolet light excites fluorescent-coated glass. This fluorescent coating emits light of a longer wave length. The intensity of the light emitted is simultaneously controlled in proportion to the intensity (strength) of the quenching infrared rays. The strength of the infrared rays is automatically and finitely controlled in strength by the density (opaqueness to light) of the photographic negative from which the positive is being printed.

The Fluoro-Dodge instrument, which employs these principles and materials, consists of components arranged in such a manner as to utilize the reactions previously described. The various densities of images in the negative control the strength of the infrared rays reaching the fluorescent coating. The resultant quenching action forms a "light positive" of the negative on the fluorescent coating. This "light positive" exposes the photographic emulsion, which may be on opaque paper or on transparent film or smooth flat glass. By regulation of the proper relationship between the ultraviolet and the infrared sources of light, it is possible to approach on all gray photographic print. Also, by correct control of the sources of light and placement of the fluorescent coating with respect to the negative, areas of features rather than finite details within areas are also dodged.

Tests have shown that if the backside (not the emulsion side) of the negative is in contact with the fluorescent coated glass, it is possible to dodge negative detail as small as 0.001 inch in diameter. At present, however, optimum results are attained when the fluorescent coating and the emulsion of the negative are 0.060 inches apart. It is claimed through demonstration of the contact-printing Fluoro-Dodge that this separation attains dodging in smaller areas than any dodging system previously available. It is further claimed that a density compression of six in a photographic gray scale can be attained by use of single-weight photographic paper, and a density compression of about nine for the same scale can be achieved by use of glass or film as base for the photographic emulsion. Considerably more density compression can be attained in a projection-type Fluoro-Dodge system. Moreover, there is no limit to the size of photographic negative, the range in its density (light transmissibility), and overall density which can be dodged, provided each area of the negative contains photographic detail.

In the present Fluoro-Dodge, the ultraviolet light source requires 15 watts. The infrared light for quenching requires 200 watts. The only other parts requiring service to maintain operation ability are a timer and air-filled transparent plastic bag employed to assure uniform contact between the emulsion side of the negative and the emulsion of the positive to be printed. Printing time with negatives of average density is approximately 8 seconds for prints made on single-weight photographic paper. The time is proportionately shorter for prints made on transparent film or glass. Fortunately, the range in this proportionality is not as great as the range in light sensitivity of the emulsion usually placed, respectively, on opaque paper and on a transparent base. The overall density or thinness (lack of density) of any negative, however, does not have an effect on the exposure time--it is the same for all negatives because uniformity is always attained, according to need, in the intensity of the emulsion-exposing light through the automatic quenching control of the infrared light.

The Fluoro-Dodge, although very new, with only demonstration models produced to date, will soon be available. It offers great promise for the users of photographs who require prints on paper, glass, and film which are uniform in color tone and detail, as usually required for mapping by precise photogrammetric methods. These results may be obtained from any negatives containing image detail, regardless of their range in density. Additional advantages of the Fluoro-Dodge lie in its simplicity, low cost, ease of operation, and effortless maintenance which is as simple as the replacement of a light globe in a socket.

Conference on Increasing Highway Engineering Productivity
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C. W. Whitcomb
Massachusetts Department of Public Works

PHOTOGRAMMETRY AS USED IN MASSACHUSETTS

Before the adoption of photogrammetry by highway engineers, I suppose Massachusetts was no different than any other State in the general method used in obtaining data for the plotting of reconnaissance plans for location studies, and preliminary plans for design and construction. Whether Massachusetts is now ahead, behind, or about on the same level as the other States in this race to get more production out of the engineer, can only be determined by a meeting such as the one that is now being carried on.

I refer to the changes that are going on as a race, and to me it surely seems like one, for unless one reads about all the new developments going on, he will find he is using last year's method, which today are antiquated.

In Massachusetts the first big change came in 1949 when the Legislature passed a $100,000,000 Highway Bond Issue, the first of a series of Highway Bond Issues totaling $750,000,000. Although we were not aware of it at the time, this series of Bond Issues enabled the Public Works Department to gear itself for the much larger program to be carried on in the next thirteen years.

It was obvious to us that in order to carry out the program for the expenditure of the 1949 Bond Issue that the old method of reconnaissance surveying would have to be abandoned and a new method employed. Photogrammetry seemed to be the answer. So in that year contracts for 150 miles of photo mapping were awarded, the map to be at a scale of 1 inch = 200 feet with 5-foot contours.

Since that time this type of surveying has been used for all reconnaissance mapping on relocation projects. The use of the maps has increased over the years as different divisions of the Department became familiar with them.

Through the use of aerial photography, the stereoscope, and the 200-scale photogrammetric maps, the location engineer is able to select the most economical location both from the construction and property damage point of view, as well as make a basic design that is safer and more pleasing for travel. The aerial photographs and stereoscope cut time-consuming field trips to a minimum and gives a far better knowledge of the area than would be possible by field trips alone. The maps are of invaulable help to the location engineer in presenting the location and basic design to the higher echelon of the Department and to the elected officials of the cities and towns involved for their acceptance of the proposal.

The maps have proven to be ideal for use at public hearings for they are very readily understood by the layman, and cover an area wide enough for the people to locate their property, or some other known point, and to study the effect of the proposed highway on their property. With this better understanding of what is proposed, and its effect, the public has shown greater acceptance of the proposed design.

The right-of-way engineers claim that the cost of the mapping is worth the use they alone get from them. They are able to plot property lines of large tracts of land on the mile wide coverage of the map, and study the value of the remaining property after the highway taking has been made.

These maps are also used in court cases to give the judge and jury a better understanding of topography and land use of the area.

The design engineers claim the 200-scale photogrammetric maps are essential for the proper study of drainage problems, and together with photographs and stereoscope the designer can obtain an excellent knowledge of the highway location and abutting areas without having to leave the office. He can also study the area beyond the limits of the preliminary plans to assure himself and others that the design of cross streets is proper and has not created hazardous conditions.

The location section is able to compute in the office the base line to be run in the field by the survey parties. Thus, two men in the office compute and check the base line using fast desk calculating machines while the four-man survey parties are making other surveys. The result of this method is that the survey chief is given a plan showing all the control points he is to use, the points the instrument is to be set over, the points to be sighted on, the angle to be turned, and the distance to measure. Also, control points on which intermediate checks are to be made, and the angle and distance to these points, as well as the control point on which the final check is to be made.

In following this information, the survey chief has a good check on his own work, and can spot any error as soon as one is made. In this base line survey no attempt is made to station the base line until the distances between P.I.'s are measured, and a check made on control points. This information is sent in to the main office and the traverse computed and adjusted (it must be of second order accuracy). The survey chief is then given all information on the base line, the length of sub-tangents, and the stations of all P.C. and P.T. It is then possible to start a number of survey parties stationing the line, taking detail and cross sections. I must add that it is not necessary on a long job to wait until a check is made on the final control point before sending in parts of the traverse.

As stated, the first big step came in 1949, and the second in 1955. Since that time it seems steps are being taken every flying season, and more steps are being studied under a research contract between Massachusetts Institute of Technology and the Massachusetts Department of Public Works and Federal Bureau of Roads. Professor Miller of M.I.T. will speak on this on another panel.

In 1955, it was decided to increase the use of photogrammetry and enter into the field of preliminary surveys. The reconnaissance surveys and preparatory work up to and including the running and stationing of the base line was to be carried on as above described. However, the survey parties were instructed not to take detail or cross sections until ordered to do so.

Base line survey work was started in the field early in 1955 on a 24-mile section of proposed highway and about the same time a contract was awarded for the preparation of 40-scale photogrammetric maps with 2-foot contours. The maps were delivered on July 9, 1955. It was planned to make the preliminary design on the maps and to plot cross sections from the 2-foot contours. To date about $8,000,000 worth of contracts have been awarded using this method and additional contracts totaling $21,800,000 are now being prepared.

The overall plan was as follows: First the base line would be run and staked in the field using the method above described. This base line would be plotted by coordinates on the photogrammetric map. The survey parties would then be instructed on what supplementary detail would be needed. This detail being kept to a minimum and being confined only to that needed for a right-of-way damage settlement, and to fit side roads, drives and walks. The cross sections plotted from the photogrammetric map would be used for advertising the projects, and after the site was cleared, ground cross sections would be taken for final earthwork payments.

You may be interested in the results of an experimental section advertised in December of 1955. The project about 6600 feet in length shows the following comparison between the field cross sections and the cross sections plotted from the 2-foot contours.

Cut & Fill	Field Section	Photo Section	Difference	Percent
Embankment	87,591	88,081	490	0.6%
Cut	72,583	74,078	1,495	2.1%

The design and plan sections reported some dissatisfaction with this method; first, the contours interfered with design work, especially where they were close together. Secondly, construction tracings had to be made

leaving off the contours, and third, the Plan Division still had the job of plotting cross sections which they claimed was time-consuming, even though it was faster than the old method; and four, no tabular record of the cross sections was available in case it was decided that the electronic computer be used to compute earthwork quantities.

We were also advised by the aerial mapping concerns that greater accuracy in the cross sections could be obtained if spot elevations were taken directly from the stereo plotter.

It was decided to test this method, so a 5 mile section of highway, that had to be relocated because of the extension of an airbase runway, was selected. Time did not permit the running of the base line before the end of the flying season. Thus, the photos were taken and the planimetric maps plotted while the base line was being run in the field. The coordinates and data on the base line was forwarded to the contractor. The base line was then plotted on the map and sections were plotted directly from the stereo model in the Kelch plotter. A check of 300 profile points between the photogrammetric profile and the ground profile showed the error as follows:

1. The plus error less the minus error showed a difference of 0.17 feet.

2. The plus error plus the minus error showed a difference of 0.86 feet.

It was noted that in general, if the center elevation was in error, this same error was carried through the cross section. That is, if the center elevation was a foot low the whole section was a foot low. This fact verified the method used by the Ohio State Highway Division of having the base line run prior to photography.

It was decided to abandoned the above methods and adopt the Ohio method. I hope I am not describing a method that will be described by Mr. Sheik later on this panel. For those of you who have not had the pleasure of reading about this method, it is briefly as follows:

The base line is run and staked in the field as described and a profile taken. Markers that will be visible on the photograph shall be placed at all P.C., P.T. and P.I.'s and at three or four hundred foot intervals along the base line. This is done prior to the photography. The profiles and coordinates of the base line are furnished to the mapping contractor, who in turn prepares a planimetric map 40-scale, construction

tracings, cross section 480 feet wide, 8-scale, both horizontal and vertical profile, and cross section record (on a department form). The average cost of the above work is about $2,800 per mile for a map 1200 feet in width.

In this system it is felt that some supplementary detail will still have to be taken by our survey parties in the field.

To date 81 miles of aerial survey has been made using this system, and between 50 and 60 miles will be flown this fall. Delivery of the maps under this system are just being made, so time has not permitted a satisfactory check.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Vinton A. Savage
Maine State Highway Commission

OBTAINING THE OPTIMUM VALUE FROM PHOTOGRAPHY AND PHOTOGRAMMETRY IN HIGHWAY ENGINEERING

For many years I have had the pleasure of being employed by the Engineering Division of the Maine State Highway Commission. During this time I have been afforded an opportunity to observe many changes which have taken place in nearly all phases of the highway industry. Engineering methods have not changed as extensively as other features in this field.

Increased design speeds and greater traffic volumes have dictated, as a part of surveying requirements, the necessity for additional detail information with respect to topography, greater width of cross section, and more extensive soils information. What does this mean with the ever pressing problem of a shortage of engineers and trained engineering personnel? It means other fields must be explored in order to obtain more efficient methods for preliminary engineering. Methods which will require a minimum of engineering man-hours.

Aerial photography found its place in highway engineering many years ago. From its early inception, location engineers have taken advantage of such photos as could be made available by soil conservation agencies, taxation maps, and strip maps made exclusive for individual projects.

Engineers recognize photogrammetry as a great step forward in highway engineering.

Several months prior to passage of the 1956 Federal Highway Act the Maine State Highway Department considered the feasibility of engaging a photogrammetric company to make a survey and to develop plans, profile, and cross sections by the use of aerial surveys and photogrammetry. On February 15, 1956 the State Highway Commission authorized such a project covering approximately 28.6 miles along the Interstate System.

From the start, this project was envisaged as a cooperative operation between the State Highway Commission and the contracting engineer (in this case, the James W. Sewall Company) in route selection, base line stake-out, and preparation of basic contract documents, specifically, plan, profile and cross section. The selection of the route was the responsibility of the State Highway Commission; the duty of the contractor was to implement this proposed route in the form of centerline stake out and basic contract documents.

The route selected was part of the proposed Interstate route from the end of the Maine Turnpike at Augusta to Clinton. This route passes through the western portion of the City of Augusta, thence through the

Town of Sidney, passes through the western portion of the City of Waterville, and continues through the Town of Benton into the Town of Clinton. This alignment presented a variety of conditions; difficult terrain, sparsely settled woodlands, farmlands, thickly settled urban regions and at least two major rivers and stream crossings. Also influencing the route selection were major swamp and peat areas and rock outcrops.

The first stage in the route selection was an alignment placed on existing U. S. Geological Survey topographic maps. These maps, to a scale of one-inch equals one-mile, while not exactly out of date, did not permit a closely defined line. While awaiting the spring flying season, the contractor made a winter flight to a scale of one-inch equals 1000 feet. These photographs were taken when the ground had a slight snow cover and were of only partial benefit. Difficulty in recognizing subsidiary roads and such controls as cemeteries limited their use. However, this flight did serve a useful purpose in defining the flight lines for precision photography.

Prior to flying for photogrammetric compilation, the contractor made an extensive study of the available control. It was decided to place this entire project on the statewide coordinate system, east zone, as specified by the U. S. Coast and Geodetic Survey. Since the available control stations were widely separated, the contractor recovered the existing stations and observed astronomic azimuths in preparation for later control surveys. Likewise, a master level system was established along the length of the project. Attention was given in the design of the photogrammetric control surveys toward their usefulness at such time as the problem of alignment stake out should arise. By these steps the contractor was in a favorable position to secure photogrammetric control.

Flights were made along the alignment in May of 1956 after disappointing delays caused by snow cover. The flights were made at an altitude sufficient to give a mapping coverage of 3200 feet wide to a scale of one inch equals 200 feet and at the same time to be suitable for the photogrammetric compilation of plan, profile, and cross sections.

The selection of the photogrammetric control was influenced by the probable position of the alignment. It was thought wise to have the control traverses cross this probable alignment in a reasonable frequent manner. Likewise, the secondary stage of levels were brought as close to the alignment as possible without a loss of mapping efficiency. The pattern of existing control left something to be desired. The traverses were generally long (one traverse was 13.5 miles in length), but quite satisfactory closures were observed on U. S. Geological and Coast and Geodetic Survey stations. Likewise, the existing level control was found to be of quite satisfactory nature.

The selection of the route which was the responsibility of the State Highway Commission was made on the 200-scale, 5-foot contour interval topographic maps as prepared by the contractor. The noting of the desired alignment took the form of plotting the points of intersections, entering the desired degree of curve, and drawing the tangents. The contractor first scaled the coordinates of the P.I.'s, then made a route calculation along the alignment entirely in terms of State coordinates. For later preparation of the plans by photogrammetric processes, the coordinates of every five stations were calculated. In addition, coordinates were obtained for P.C.'s, P.I.'s, and P.T.'s.

In the stake-out of the alignment the contractor computed the intersections of the alignment with his various traverse controls. The principal was adopted of running an initial traverse as close to the alignment as possible between two such intersections. This traverse was closed and adjusted; the station coordinates then served as a means for moving onto the desired alignment. In the case of curves liberal use was made of sub-tangents. Through these steps, it was felt that the final centerline stake-out would faithfully reflect the alignment as initially calculated. The location of full stations and plus-50's were performed in the usual routine manner. Likewise, the line was profiled and alignment benchmarks established according to the specifications of the highway commission.

Another important portion of the stake-out operations was the noting of topography. Differing, however, from the usual ground surveying route topography, this process was designed to supplement photographic information. For example, structure locations and shapes were given limited attention, but such details as fence locations were given exhaustive treatment. The former items are clearly visible in photographs while the latter can possibly be overlooked. Also significant breaks in the topography were carefully noted for the guidance of those performing the subsequent photogrammetric operation.

Meanwhile, the alignment elements were carefully laid out on manuscript maps for reinsertion into the Kelsh Plotters. Using the breaks in the terrain as transmitted from the field, the cross section stations were noted. Carefully drawn prependiculars (or radials) were drawn directly on the manuscript. After setting up the spatial model, the operators noted spot elevations along the cross section lines. Cross section readings were noted, both at specific intervals and at significant breaks.

This process of reading spot elevations gives, it is felt, somewhat superior information in that the operator's attention is focussed on a particular point. Cross sections deduced from contours alone seems to be decidedly inferior. Thus the photogrammetrist, after having correlated

the optical relief model to the ground control, reads elevations at points given results not dissimilar from those resulting from the process of reading a rod at the same point. His measuring device (in this case a tracing table) is positioned over the plotted point and the corresponding elevation read on his vertical gauge. Incidentally, the perpendiculars and radials on the manuscript are, insofar as drafting tolerances allow, true representations of what cross sections should be. The entire process can be likened to a superbly calibrated relief model--the terrain in scaled minature--abetted by a precision implement for reading elevations. Thus position data is derivative from the manuscript and elevations from the tracing table--a calibrated elevation device.

The cross section information was entered onto specially prepared note forms which were very similar to a well-kept set of notes without the usual backsight, foresight, and height of instrument notings. These served as the basis for the plotting of the cross sections, as well as presenting a permanent record of the data.

While the model was in a calibrated position, the planimetric information (or "topography") was taken off. This procedure was supplemented immediately by the observations entered in the notebooks by the field crews. This planimetric information provided the basis for the plan portion of the basic contract documents.

In this particular project the contractor also determined property lines and so placed such on the plans. These boundaries were determined by a combination of field inspection and research in the town and city records.

Thus the presentation of the final results took the form of a complete set of plan-profile sheets supplemented by cross sections.

Plans were developed to a scale of 1-inch = 50 feet, profile 1-inch = 50 feet horizontal and 1-inch = 5 feet vertical with both vertical and horizontal scale of 1-inch = 10 feet for cross sections.

Aerial photography, in the final analysis, is of unlimited value for many reasons, such as highway location, public hearings, drainage problems, soils interpretation, and right-of-way matters.

Photogrammetry provides relief to certain phases of engineering allowing State highway engineering personnel to concentrate on ultimate location, design, and construction features.

It is my belief that plans developed to a scale of 200 feet to the inch with supporting five-foot interval contours provided information of unlimited value in determining the final location for a highway. Any reflection in economy for plans developed by photogrammetry beyond the above mentioned limits cannot be measured directly in dollars, but rather in the saving of engineering man-hours which in turn may be applied to other phases of the highway industry.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

Robert H. Sheik
Ohio Department of Highways

OBTAINING THE OPTIMUM VALUE FROM PHOTOGRAPHY AND PHOTOGRAMMETRY IN HIGHWAY ENGINEERING

Aerial photography and photogrammetry have been proved conclusively to be useful tools to the highway engineer in expediting highway projects. In the application of these tools time has been saved, engineering manpower conserved and great economies achieved--all without sacrificing accuracy.

Once the usefulness of a device has been proved and accepted, the next logical step is to determine its optimum value; rather, obtain its optimum value. In accomplishing this with aerial photography and photogrammetry--as in obtaining the optimum value from any device--they must be given the widest possible application. Specifically, the optimum value of these useful tools to the highway engineer can be obtained by applying them to all phases of highway engineering: location, design, right-of-way construction and operations.

LOCATION

In determining highway location through the use of photography and photogrammetry, small scale photography and U. S. Geological Survey topographic maps are the initial aids. They are used to make a reconnaissance survey of a broad area, which provides a comprehensive basis upon which all feasible routes may be carefully compared--allowing the consideration of all factors affecting location, including design standards.

Subsequently, larger scale photography (1-inch = 800 feet) is provided to allow a closer study of one or more of the preferred alternate locations. Finally, a 1-inch = 200 feet topographic map with 5-foot contours is prepared for detailed study of the chosen location--or even for alternates, where selection cannot be readily made. In flat terrain the topographic map would not be needed; however, in built up urban areas a planimetric map may be necessary.

With the aid of this map (1-inch = 200 feet, 5-foot contours) and photography the engineer can pin point the center of the proposed location; prepared profiles; establish grades; study soils conditions, land use and drainage; determine work limits, and prepare reasonably accurate estimates.

Other products of aerial photography which are useful in determining line are: a photo mosaic with the proposed line superimposed; aerial obliques; enlargements of built-up areas; and an artist's concept of the finished highway drawn realistically on an aerial photograph.

Since in some States final determination of the location of a new facility is by law subject to public scrutiny of engineers' proposals, certain products of aerial photography are invaluable aids in winning public acceptance. The adage "a picture is worth a thousand words" applies: It has been proved that such visual aids as a photo mosaic showing the proposed line or an aerial photograph replete with artist's rendering of the proposed new facility lend immeasurable assistance to the engineer in his task of justifying the proposed line to the lay public.

DESIGN

Aerial photography and photogrammetry, when applied to the design phase, provide planimetric maps, cross section data, and site plans—considerably speeding up the production of all three.

Since it is always necessary to stake and reference a centerline and establish benchmarks prior to construction, it should be done at this stage to provide control for the aerial survey to be used in design. The line is signalized every 300 feet on actual centerline stations, benchmarks are established and elevations taken on centerline at each station. In placing control for the wing points for this survey careful consideration should be given for its possible use for photogrammetry after completion of construction.

Staking the centerline at this time not only insures accuracy of the survey but permits taking soil samples at an early date, permits negotiators to make early contact with property owners, and enables engineers to review location on the ground and make field inspections during design. Other advantages of staking early are: the same survey crew locates property lines that cannot be identified in the photos and obtains the names of owners; the survey crew also obtains information relative to underground drainage, utilities, etc., not observable from the air.

The flight for the survey to be used in design provides photography from which a planimetric map 1-inch = 50 feet is compiled. This map is traced on cloth and becomes the line sheet for detailed construction plans.

Concurrently with plotting the topography, necessary information for cross sections is taken from the photogrammetric plotter. These cross sections are obtained by reading the elevation of a definite point to the nearest 0.1 foot and not by interpolation from a contour map. The sections are taken at true right angles to centerline and are extended well beyond the right-of-way limits. This permits some shift of centerline during design without putting the models back into the plotter.

(The Ohio Department of Highways is now using an attachment to the Kelsh plotter, developed as a research project, that permits the operator to record and print automatically on punch cards pertinent data such as

station, elevation and distance from centerline to the nearest 0.1 foot along a cross section. This device conserves manpower and increases accuracy. Previously, this data was plotted on a manuscript: the distance out from centerline was then scaled and read along with the recorded elevation to someone plotting the cross section.)

The punch cards with design data are then sent to the electronic computer for computation of earthwork quantities, slope stakes, etc.

Maps of sites for structures and interchange areas are prepared at a scale of 1-inch = 50 feet with 2-foot contours while the models are in the plotter for the planimetric map and cross section. This map is copied in the photo laboratory to a scale of 1-inch = 20 feet for the convenience of the bridge design engineer and is traced on cloth for the site plan.

Design then proceeds in the conventional manner except that the engineer has much more information available from the maps and photographs than he could possibly have from ground surveys.

Controlled scale photography alone has proved to be very useful in flat or level country, particularly so for widening and resurfacing projects. For this control the centerline is staked and signalized every 300 feet including points on curves and the points of intersection.

Photography taken at a scale of 1-inch = 200 feet is enlarged to 1-inch = 50 feet. With the aid of a tilting easel the photography is rectified when projected to fit the control. The final picture is made on water resistant paper having suitable dimensional stability. The planimetry is then traced from the photograph on cloth for the line sheets of the construction plan.

RIGHT-OF-WAY

The acquisition of right-of-way, one of the many items to be considered in expediting any highway construction program, can also be greatly aided by the application of aerial photography and photogrammetry.

The photographs and maps prepared for location studies can be used for right-of-way estimates, which are needed for determination of location. Work limits can be determined from the map to permit early preparation of right-of-way plans and establishment of taking limits. Property lines that are visible in the photography can be provided to the plotter operator and can be indicated on the planimetric map or line sheet, thereby expediting right-of-way plans.

Having the centerline located in the field and the right-of-way limits established at an early stage, the traverse, bearings and parcel areas can be computed by the electronic computer and actual negotiations can be underway before design is completed.

Enlargements to scale of 1-inch = 50 feet of the photography used in design plus the artist's rendering of the proposed project are proving very helpful to the negotiators in securing right-of-way.

Oblique photography, enlargements of vertical photography and in some instances maps are valuable in appropriation cases to acquaint the judge and jury of the actual condition.

Certain photos taken during construction are helpful to right-of-way personnel in settlement of cases that have not been settled prior to construction and in settlement of damage claims due to construction.

CONSTRUCTION

Aerial photography is useful in the construction phase in that it provides a pictorial account of the progress of special or unusual projects or projects of particular interest to the public.

Final cross sections are taken by aerial photogrammetry with the information being placed on punch cards automatically from the Kelsh plotter. These cards are then sent to the electronic computer to compute earthwork quantities for final payment accurately and quickly.

If the control points for the design photography were wisely chosen they can be used for the photography for final cross sections. Only the finished centerline need be signalized. This photography can be taken in the summer as the area has been cleared by construction, thereby providing photographic and photogrammetric work for a season that is normally considered slack in the aerial survey business.

The available maps and photography are useful to the contractor as there is much more detail in the photos than is shown on the plan sheets. The topographic map and overlapping photos are helpful in observing soils, locating borrow pits and classified embankment material. They are also used in preparing bids, prosecuting the work and publicizing the contractor's achievements.

OPERATIONS

Photography of the completed project is an aid to the maintenance engineers in observing pavement and roadway conditions, erosion and drainage problems. This photography is also studied by the design engineer to observe any deficiencies in the design.

The traffic engineer can use aerial photos in traffic studies of roadway facilities and the movement of traffic on the facilities. An overall view can be obtained of traffic movements and the physical conditions which affect those movements in the area surrounding a point where traffic is experiencing difficulty.

Photos can be used to show the relative use of roads in the vicinity of large generators of traffic. The location of points of congestion, the time at which congestion occurs, and apparent causes of congestion can be identified from the aerial photos.

Delay at specific points of congestion--both total delay to all vehicles and maximum and average delay to each vehicle--can be determined from the movement of vehicles as shown on photos taken at regularly-spaced intervals.

Where construction plans are not available or not up to date, a condition diagram can be made from the photos.

Limited and controlled access projects can be photographed to compare the access at one date to that of a later date.

MANY USES

Many uses for photography and photogrammetry in highway engineering have been cited and no doubt there are many other applications. As has been stated, there is no question any more as to their usefulness in expediting highway projects, conserving engineering manpower and achieving economies--all without sacrificing accuracy. Now with the integration of aerial photogrammetry and electronic computers their importance as tools for the highway engineer are greatly increased.

To gain acceptance of these tools by the engineers it was necessary to supply their needs without changing the procedures for planning, surveying and design wherever possible. Now that these tools have been accepted and considerable sums of money have been invested in them, attention should be given to operating them efficiently.

To obtain the most from aerial photographs and photogrammetry much thought must be given to scheduling since aerial photography can be taken only at certain times and under certain conditions to provide the quality of photos necessary for interpretation or the desired maps. Perhaps more thought should be given to clearing and grubbing contracts to permit taking of aerial photography for design purposes in densely wooded areas and at times when foliage would interfere with the photography.

To obtain the most from the integration of photogrammetry and electronic computers it may be helpful to revise our specifications as to methods of payment, measurement of quantities, etc., also our method of design and preparation of construction plans. This of course could be done only by maintaining a high level of design and construction.

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

A. O. Quinn, Chief Engineer
Aero Service Corporation

THE PHOTO CONTOUR MAP - NEW AID FOR ENGINEERS

I should like to bring to your attention a new map especially designed to provide a maximum amount of information for map users. It is called the photo contour map. Produced by photogrammetric and photographic techniques, this new map shows both contour lines and a photographic image of all planimetric and cultural details of the area.

The photo contour map is a true map in every respect; an orthographic projection showing both contours and complete air photo detail. It is not a mosaic with contour lines superimposed. On the contrary, in compiling the photo contour map, detailed corrections are made for tilt, topographic relief and scale for each photograph. A map accuracy is achieved which is impossible in the preparation of the most exact photo-mosaic.

Figure 1, which reproduces a photo contour map, shows the vast amount of map detail now available for the map user. In preparing a conventional, line-drawn map it is impossible to include all the details seen in the photo contour map. Costs would be prohibitive.

The photo contour map is especially useful in the field. Now a scheme for a highway or subdivision can be planned in the office, then field or design personnel can visit the area and exactly locate the critical points. They can quickly position themselves with this new map, referring to readily recognizable planimetric features and spotting elevations and drainage patterns from the contour lines of the map. In addition, soils and outcrop data can be correlated with the basic map with greater facility and accuracy, and this new map is particularly well suited to hydrological and drainage studies.

This new map is the result of an ingenious combination of photogrammetric principles. The original developments were made by the R. M. Towill Corporation of Honolulu, Hawaii, and photo contour maps can be obtained only from Towill or their exclusive licensee, Aero Service Corporation of Philadelphia.

Compilation of the photo contour map follows standard photogrammetric mapping procedures. Additional field control is not required. A map manuscript is prepared in the usual manner, and the contours are drawn. A stereo-plotting instrument with which the tilts of each photo can be recorded is used. Planimetric features are not shown on the manuscript, since they will appear as photo-images on the final map sheets.

After the contoured manuscript sheet has been inked or scribed, the photographic processes begin. These reverse the usual photogrammetric mapping procedures whereby a pair of photographs is projected to determine ray intersections for the compilation of the map. In the photo contour map process, the air photos are projected onto the manuscript again in such a way that distortions caused by tilt, topographic relief and scale differences are eliminated. This is done through a specially designed projector with which the air photos can be oriented according to the tilt data from the stereo-plotter. This removes the tilt effects. The projector can be raised or lowered to produce photographic images at a common scale, regardless of differences in elevation, throughout the areas to be mapped.

Relief corrections in the air photos are made for each contour interval, as shown in Figure 2. Each contour interval must be masked and then uncovered at the proper time for the exposure upon a sensitized base. Special film and photographic techniques are used to accomplish this.

Six bands have been exposed in Figure 2, at different vertical settings for the projector. In sequence, all bands will be exposed thus to produce the composite final product seen in Figure 1.

Note that the accuracy of the method is not affected by the steepness of the terrain. Each contour band or strip is individually corrected, regardless of its position or location on the model. Of course, in very steep areas, where the contours are separated by less than .04 inches on the map, usual mapping procedures would be followed. These permit showing and mapping index contours.

The final photo contour map is a photo copy. Contours can be shown as black or white lines, or a combination of both. The contour heights, names of features, border information and other data can be added photographically. Individual photos can be combined to produce sheets at any required size. Reproducible halftone transparencies on film can be produced from the copy negatives used for the production of the photo contour maps. Of course, in addition to this, prints, film positive prints, negative film copies, and reproducible halftone transparencies on film can be prepared from these negatives.

There are no photographic tricks in the process. The success of the work depends upon very accurate stereophotogrammetric plotting of the topography plus the skillful application of photo laboratory and drafting techniques. Inaccurate work is quickly revealed by mismatches in contours and planimetric features.

Standard map accuracy can be achieved by the photo contour map. Recent specifications prepared by the Bureau of Reclamation for a photo

contour map project in northern California at a scale of 1-inch = 200 feet, showing 10-foot contours, under "Map Accuracy" states--"Ninety-five percent (95%) of all well-defined cultural and drainage features shall be within ten (10) feet of true position as measured from the nearest projection grid and field controls. The accuracy of plotted contours shall be field checked as provided in Paragraph B-10. Ninety percent (90%) of all contours shall be within one-half the basic contour interval and no contour shall be more than one full contour interval from true elevation; except that in areas where the ground is completely obscured by dense brush or timber, ninety percent (90%) of all contours shall be within one contour interval of correct elevation and no contour shall be more than two contour intervals from correct elevations."

A remarkable feature of this new map is that it is virtually self-checking. The position of the contours shown on the map sheet must track or follow the planimetric features. If the contours do not, it is immediately apparent that there is an error in the work. On the other hand, if the contours do track the planimetric features such as roads and streams, it indicates that the map measures up to high standards of accuracy. This particular feature should be of major importance to clients who feel that it is necessary to make detailed field checks of line drawn maps.

Figure 3 illustrates a photo contour map in which the contours have been corrected to the 185 meter contour at approximately the center of the map. The topographic features in the vicinity of the 185th contour do track the visible drainage and planimetry. However, in areas away from the 185 meter contour, errors in the topography are immediately seen. Similarly, Figure 4 shows a correction for the 200 meter contour at the left side on the map. Figure 1 shows the same area when proper techniques are used. All topography tracks the visible drains and planimetric features in Figure 1.

The photo contour map costs somewhat more than the usual line drawn map. However, we feel that the many advantages gained from this type of map far exceed the additional costs involved. In areas of relatively dense planimetric features, such as urban and heavily populated suburban areas, there will be substantial saving of time and money since the photo contour map will show the location of all planimetric features without the expenditure of valuable drafting time.

A very rough estimate of costs would be:

2-ft. contours at 1-in. = 100 ft.	approximately	\$5.00 to \$10.00 per acre
5-ft. contours at 1-in. = 200 ft.	"	\$2.50 to \$ 6.00 per acre
10-ft. contours at 1-in. = 400 ft.	"	\$1.00 to \$ 3.00 per acre
20-ft. contours at 1-in. = 500 ft.	"	\$0.50 to \$ 1.00 per acre

These figures are dependent upon ground conditions, requirements for control, the quantity of maps required, and other considerations. Each job should be planned and priced based upon specific conditions and needs.

At Aero Service we are very enthusiastic about the photo contour map. We believe that this map has been well designed to suit the needs of the map user. We think it will be used widely by engineers, geologists, foresters and others, to plan and develop a wide variety of projects. The R. M. Towill Corporation has completed many maps for sugar plantations in Hawaii and for many of the military bases in the Islands and elsewhere in the Pacific. They have a great deal of work for the Territorial Highway Department of Hawaii which has proven to be most useful in highway work. In our work with the Towill process, we have found that absolute accuracy and a high degree of technical skill is essential. The final product is the fulfillment of the engineer's and photogrammetrist's dream for the maps of the future.

In summary, we believe the photo contour map will find wide use for these reasons:

(1) Self-checking through visual inspection.

(2) Reduced field checking time; all the information of the aerial photograph is brought to your desk.

(3) Drafting time is reduced up to 50 percent.

(4) Photographic reproductions to the scale you require from one negative.

(5) One base map will satisfy engineering requirements for planning and design.

(6) Accurate to national mapping standards.

We shall be glad to discuss the process and its applications to specific mapping problems.

Photo contour map. (corrected for tilt and relief)

Sample of zone exposure.

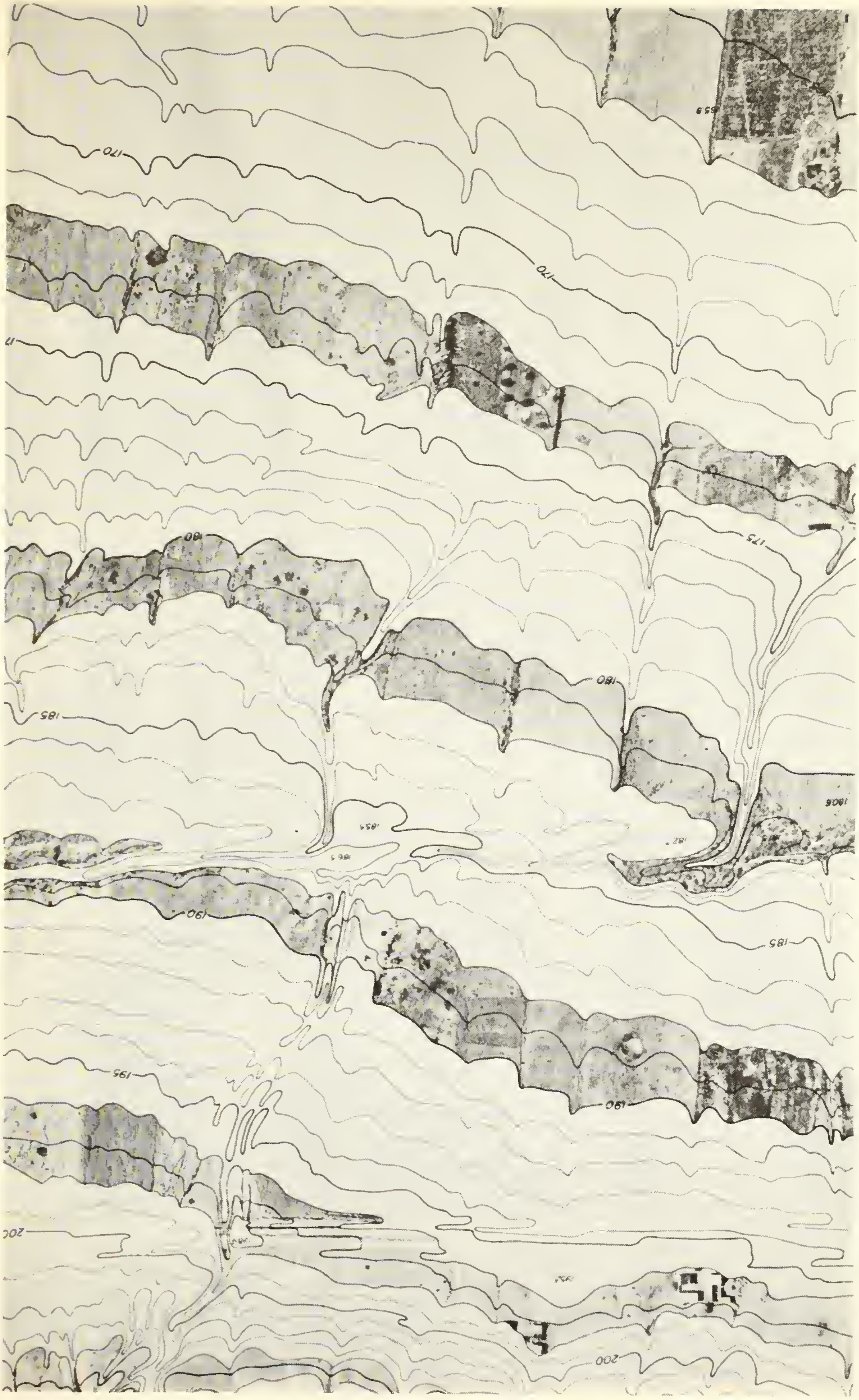

Figure 2

Rectified photograph with superimposed contours. (correct for the elevation of the 185 meter contour)

Figure 3

Rectified photograph with superimposed contours. (correct for the elevation of the 200 meter contour)

Figure 4

Conference on Increasing Highway Engineering Productivity
Boston, Massachusetts - September 17-18-19, 1957

George E. MacDonald
Lockwood, Kessler and Bartlett, Inc.

OBTAINING OPTIMUM VALUE FROM PHOTOGRAPHY AND PHOTOGRAMMETRY

Mr. Chairman, and participants, it is a pleasure and honor to be invited to talk here today. My assigned subject "Obtaining Optimum Value from Photography and Photogrammetry" is not the easiest in the world to speak on, especially in front of Mr. Pryor, who I am sure many of you have heard cover this matter on other occasions very comprehensively and competently. So if you get the uneasy feeling as I proceed that you have heard this before, do not be too concerned, because you probably have.

Perhaps if we are going to talk on the application of photogrammetry to highway engineering it would be helpful to first outline what kind of highway we are thinking of, and if we should say that this conference is mainly concerned with the Interstate System, then we find that the approved geometric design standards for the Interstate highways contain the following general provisions:

"Divided highways should be designed as two separate one-way roads to take advantage of terrain and other conditions for safe and relaxed driving, economy and pleasing appearance. All known features of safety and utility should be incorporated in each design to result in a national system of Interstate and Defense highways which will be a credit to the Nation. These objectives can be realized by conscious attention in design to their attainment."

The success of a highway designer in meeting these objectives is dependent not only on his experience, skill, and imagination, but also upon the amount and reliability of the information he is given to work with. As is obvious from the description of the desired geometrics, even in the design stage a wide swath of terrain is needed for study. At this stage I do not believe I need waste your time in trying to convince you that photogrammetry, rather than ground surveys is the logical choice for taking topography. It is the only medium that combines, speed, reasonable cost, accuracy, and qualitative and quantitative information, over a width wide enough to insure that the designer is not overlooking the best solution for lack of coverage.

The Bureau of Public Roads has also established a set of "Criteria for the selection of routes for the National System of Interstate Highways." It might be interesting to briefly review them to see where the use of aerial photography and photogrammetry will aid in establishing the desired locations.

Part 3 "Density of rural population"

"Routes should traverse the country's most populous bands of rural territory." Aerial photography will show the location and density of farm dwellings.

Part 4 "Distribution of the whole population"

"Routes should have their principal termini in the larger cities and also pass enroute between these termini through or very close to the denser clusters of population in small towns and populous rural areas." Aerial photography shows all villages and hamlets, and indicates the routes between them.

Part 5 "Relation to manufacturing activity"

"The routes selected should provide transportation facilities for as much as possible of the manufacturing industry of the country. Locations where manufacturing activity exists in greatest volume are the points of origin and destination of large volumes of motor truck traffic for which service should be provided, as well as for passenger car traffic." Aerial photography properly interpreted will show not only existing manufacturing activity, but desirable sites for future plant locations.

Part 6 "Relation to agricultural production"

"Interstate Systems should traverse to the maximum extent possible the areas of high per acre value in marketed crop production." Aerial photographic interpretation will distinguish high value row crops from grains, hay and silage, pasture and woodland. It will also aid in the location of a line to minimize property damage and severance.

Part 9 "Relation to military and naval establishments and war industry"

"Routes of the Interstate System should be selected to serve the highway movement to and from military and naval establishments and war industries." Aerial photography will show the location of unmapped establishments and aid in the location of interchanges and access roads.

Part 11 "Relation to principal topographic features"

"Consideration of topographic features is important in the selection of some Interstate System routes. Conformation of the land and the courses of principal rivers may influence to some extent the location of certain routes." A full appreciation of topography is afforded by viewing the relief model of a stereoscopic pair of aerial photos.

A few years ago I had the good fortune to be entrusted with the survey and location of a 250 mile railroad through the South American jungles. With existing maps mere skeletons, it was necessary to secure reconnaissance maps of an area about 25 by 250 miles. We used a combination of aerial photography and the Airborne Profile Recorder to produce photogrammetric maps. The latter is a downward directed radar device which continuously records variations in the earth's surface contours on a paper tape. In due time, by a combination of ground exploration, stereoscopic study of the aerial photos, and the photogrammetric maps the route was projected, estimated and the project financed. The press became interested, and one of the great weekly news magazines, after an exhaustive interview, published an account of the engineering. As you might guess, they ignored every facet of the engineering but the use of radar, and I am sure the readers were convinced that the railroad was designed by radar.

There might be a lesson from this for we assembled here today. The application of electronic computers to highway engineering over the past two years has received so much favorable publicity that the idea that the computer will design the highways is by no means rare. Some of the more enthusiastic and best publicized advocates are developing systems whereby aerial photographs, instead of being worked up into our familiar and easily understood topographic maps, are being read by stereoscopic instruments, recorded on punched tape, punched cards, or magnetic tape, and filed away. When you want a cross section you take a picture of an oscilloscope image, or have an electro-mechanical plotter draw one up for you. Note that you can not get any cross section, normal or skew that you may need, but only those recorded. While many useful computations can be made from such recorded data, I would like to point out that much of the pertinent information on the photographs is omitted. The memory tapes can show only the terrain relief, they can not record any cultural data such as type, number, and density of buildings, the street and road network, the land use, the drainage pattern, and the surface geology. Although earthwork is an important consideration in highway design, except in a wilderness it is not paramount and the actual computation of quantities is performed by sub-professional people.

It would seem that the chief advantage of the stereo-memory-computer system is their ability to yield certain numerical quantities relating to earthwork and grades. However, considering that the location and design of a highway is both an art and a science, whose practitioners must weigh and balance many other factors besides grades and earthwork; and that aerial photos record much of this information, I would suggest that the optimum value from aerial photography is to be obtained not by dissecting and storing it in inaccessible memory tapes and cards, but by converting it to a medium that shows most of the information on the photograph in one place,

to a convenient size, requiring no mechanical or electrical gadgets for interpretation, and easily understood by anyone reading English, in short, the familiar, tried and proven, photogrammetric topographic map.

The designer working with a topographic map can integrate the information therein contained with his previous experience. He can readily see several miles of the project on one large table. He can try and find out the effects of changes in alignment. Most important, he can see right in front of him the whole story with no need to wait for a cross section or profile from a computer center. While in complete sympathy with all efforts to lighten the burden of engineering computations, I believe we should be wary of any proposed systems that deprive the designer of the benefits of a detailed topographic map.

Registered Attendance

NATIONAL CONFERENCE ON INCREASING HIGHWAY ENGINEERING PRODUCTIVITY

Somerset Hotel - Boston, Massachusetts
September 17-18-19, 1957

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